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U.S. Department
of Transportation
**National Highway
Traffic Safety
Administration**

Robotics Use in Motor Vehicle Manufacture

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16. Abstract

The automobile industry has, historically, been a major developer and user of automation and industrial robots. There have been significant technological changes in automation and robots and a steady increase in their utilization in the automobile industry worldwide. The basic technology of industrial robots is presented. Patterns of usage and current robot populations are shown for the worldwide auto industry. Other significant automation concepts are also covered. Projected usage of robots under several assumptions are developed. New technology development requirements are identified and current research efforts are described. The impacts of continued growth in robot utilization on labor, skilled trades, capital requirements, plant layouts, cost savings and productivity are described. The improved capabilities of robots and automation, in combination with an increase in their utilization, will reduce the cost of manufacturing automobiles. Capital investment requirements for automation and robots, especially through the mid-1980's, will be high. No significant advantage in technology now exists in any particular auto manufacturing company or country. The major advantages, at present, are those which accrue from using more robots than one's competitors.

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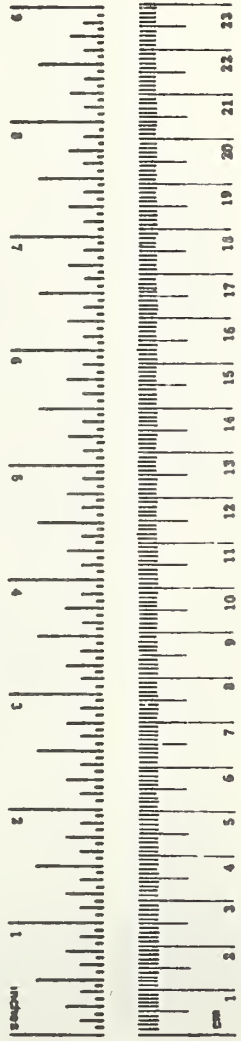
METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.96	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures. Price $2.25, SD Catalog No. C13.10:286



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
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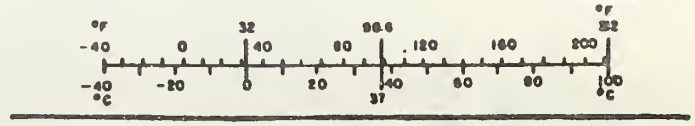
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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INTRODUCTION

The automobile industry has, historically, been a major developer and user of automation and industrial robots. In 1909, Henry Ford automated the movement of automobiles through assembly operations by adapting the continuously moving conveyor (which he had seen used in the meat packing industry) for transporting the chasses of Model T automobiles past a series of work stations. In 1922, A.O.Smith developed a mechanized automobile frame manufacturing plant.

In 1925, F.G.Wollard developed, in England, the concept of the transfer machine, that is, automatically transferring parts through a series of machine tools. The concept was first used in 1927 by Morris Motors of England; it was technically but not economically successful. In the 1950's, George C. Devol developed the concept of the digitally controlled manipulator, or industrial robot. A patent was granted in 1961 to Devol for "Programmed Article Transfer" and in the same year, the first production installation of an industrial robot was made in a U.S. automobile manufacturer's die casting plant.

The years since the 1900's, the 1920's and even since the 1960's have seen significant technological changes in automation and robots and a steady increase in their utilization in the automobile industry worldwide. The 1980's will see continued technological changes and a continued increase in utilization, especially in industrial robots.

For instance, transfer lines have borrowed the technology of the robots; the "programmable transfer line" is now a reality. The robot population in the U.S. automobile industry, which was about 1,065 units at year end 1980, may exceed 35,000 units by 1990 (General Motors alone estimates that its robot population may reach 14,000 by 1990). New developments in sensory control and other specialized capabilities will enable robots to perform many tasks in the automobile factories which presently must be done by humans. Microelectronics and computers will facilitate automating of other manual operations.

The improved capabilities of robots and automation, in combination with an increase in their utilization, will reduce the cost of manufacturing automobiles. The number of manhours of direct labor per car will be reduced, while the number of manhours per car of indirect labor to maintain and repair the automation and robots will increase (but not in the same proportion as the direct labor reduction). Capital investment requirements for automation and robots, especially through the mid-1980's, will be high.

INDUSTRIAL ROBOT TECHNOLOGY

The Robot Institute of America (RIA), which is the U.S. trade association representing the manufacturers, distributors, suppliers and major users, defines an industrial robot as "a reprogrammable multi-functional manipulator designed to move material, parts, tools or specialized devices, through variable programmed motions for the performance of a variety of tasks."

The RIA further classifies industrial robots by type, as follows:

TYPE A: Programmable, Servo-Controlled, Point-to-Point

TYPE B: Programmable, Servo-Controlled, Continuous-Path

TYPE C: Programmable, Non-Servo Robots for General Purpose

TYPE D: Programmable, Non-Servo Robots for Die Casting and Molding Machines

TYPE E: Non-Programmable, Mechanical Transfer Devices (Pick-and-Place)

Industrial robots, regardless of type, generally consist of several major elements: the manipulator or mechanical unit which actually performs the manipulative functions; the controller or "brain" which stores data and directs the movement of the manipulator and the power supply which provides energy to the manipulator.

The manipulator is a series of mechanical linkages and joints capable of movement in various directions to perform the work of the robot. These mechanisms are driven by actuators which may be pneumatic or hydraulic rotary or linear actuators or electric motors. The actuators may be coupled directly to the mechanical links or joints or may drive indirectly through gears, chains or ball screws. In the case of pneumatic or hydraulic drives, the flow of air or oil to the actuators is controlled by valves mounted on the manipulator.

Feedback devices are installed to sense the positions of the various links and joints and transmit this information to the controller. These feedback devices may simply be limit switches actuated by the robot's arm or position measuring devices such as encoders, potentiometers or resolvers and/or tachometers to measure speed. Depending on the devices used, the feedback data is either digital or analog.

The controller has a three-fold function: first, to initiate and terminate motions of the manipulator in a desired sequence and at desired positions; second, to store position and sequence data in memory; and third, to interface with the "outside world".

Robot controllers run the gamut from simple step sequencers through pneumatic logic systems, diode matrix boards and electronic sequencers to microprocessors and minicomputers. The controller may be either an integral part of the manipulator or housed in a separate cabinet.

The complexity of the controller both determines and is determined by the capabilities of the robot. Simple non-servo (Types C and D) devices usually employ some form of step sequencer. Servo-controlled (Types A and B) robots use a combination of sequencer and data storage (memory). This may be as simple as an electronic counter, patch board or diode matrix and series of potentiometers or as sophisticated as a minicomputer with core memory. Other memory devices employed include magnetic tape, magnetic disc, plated wire and semiconductor (solid state RAM). Processor or computer based controller operating systems may be hard wired, stored in core memory or programmed in ROM (Read Only Memory).

The controller initiates and terminates the motions of the manipulator through interfaces with the manipulator's control valves and feedback devices and may also perform complex arithmetic functions to control path, speed and position. Another interface with the outside world provides

two-way communications between the controller and ancillary devices. This interface allows the manipulator to interact with whatever other equipment is associated with the robot's task.

The function of the power supply is to provide energy to the manipulator's actuators. In the case of electrically driven robots, the power supply functions basically to regulate and filter the incoming electrical energy. Power for pneumatically actuated robots is usually supplied by a remote compressor, which may also service other equipment.

Hydraulically actuated robots normally include a hydraulic power supply as either an integral part of the manipulator or as a separate unit. The hydraulic system generally follows straightforward industrial practice and consists of an electric motor driven pump, filter, reservoir and, usually, a heat exchanger (either air or water).

There are significant differences in operation, capability and, to some extent, physical characteristics among the various types of industrial robots. The typical operating sequence of a Type A or Type B robot (programmable, servo-controlled, point-to-point or continuous-path) is as follows:

> Upon start of program execution, the controller addresses the memory location of the first command position and also reads the actual position of the various axes as measured by the position feedback system.
>
> These two sets of data are compared and their differences, commonly called "error signals", are amplified and transmitted as "command signals" to servo valves for the actuator of each axis.

The servo valves, operating at constant pressure, control flow to the manipulator's actuators; the flow being proportional to the electrical current level of the command signals.

As the actuators move the manipulator's axes, feedback devices such as encoders, potentiometers, resolvers and tachometers send position (and, in some cases, velocity) data back to the controller. These "feedback signals" are compared with the desired position data and new error signals are generated, amplified and sent as command signals to the servo valves.

This process continues until the error signals are effectively reduced to zero, whereupon the servo valves reach null, flow to the actuators is blocked and the axes come to rest at the desired position.

The controller then addresses the next memory location and responds appropriately to the data stored there. This may be another positioning sequence for the manipulator or a signal to an external device.

The process is repeated sequentially until the entire set of data, or "program" has been executed.

The significant features of Type A and B robots are:

The manipulator's various members can be commanded to move and stop anywhere within their limits of travel, rather than only at the extremes.

Since the servo valves modulate flow, it is feasible to control the velocity, acceleration and deceleration of the various axes as they move between programmed points.

Generally, the memory capacity is large enough to store many more positions than a non-servo robot.

Both continuous path and point-to-point capabilities are possible.

Accuracy can be varied, if desired, by changing the magnitude of the error signal which is considered zero. This can be useful in "rounding the corners" of high-speed continuous motions.

Drives are usually hydraulic or electric and use state-of-the-art servo control technology.

Programming is accomplished by manually initiating signals to the servo valves to move the various axes into a desired position and then recording the output of the feedback devices into the memory of the controller. This process is repeated for the entire sequence of desired postions in space.

Common characteristics of Type A and B robots include:

Smooth motions are executed, with control of speed and, in some cases, acceleration and deceleration. This permits the controlled movement of heavy loads.

Maximum flexibility is provided by the ability to program the axes of the manipulator to any position within the limits of their travel.

Most controllers and memory systems permit the storage and execution of more than one program, with random selection of programs from memory via externally generated signals.

With microprocessor or minicomputer based controllers, sub-routining and branching capabilities may be available. These capabilities permit the robot to take alternative actions within the program, when commanded.

End-of-arm positioning accuracy of 1.5 mm (.060 in.) and repeatability of ± 1.5 mm (± .060 in.) are generally achieved. Accuracy and repeatability are functions of not only the mechanisms, but also the resolution of the feedback devices, servo valve characteristics, controller accuracy, etc.

Due to their complexity, Type A and B robots are more expensive and more involved to maintain than Type C and D robots and tend to be somewhat less reliable.

Type A, programmable, servo-controlled, point-to-point robots are used in a wide variety of industrial applications for both parts handling and tool handling tasks.

Significant features of the Type A robot are:

For those robots employing the "record-playback" method of teaching and operation, initial programming is relatively fast and easy; however, modification of programmed positions cannot be readily accomplished during program execution.

Those robots employing sequencer/potentiometer controls tend to be more tedious to program; however, programmed positions can be modified easily during program execution by adjustment of potentiometers.

The path through which the various members of the manipulator move when traveling from point-to-point is not programmed or directly controlled in some cases and may be different from the path followed during teaching.

Common characteristics of Type A robots include:

High capability control systems with random access to multiple programs, subroutines, branches, etc., provide great flexibility to the user.

These robots tend to lie at the upper end of the scale in terms of load capacity and working range.

Hydraulic drives are most common, although some robots are available with electric drives.

The second type of servo-controlled robot is the Type B, programmable, servo-controlled, continuous-path. Typically, the positioning and feedback principles are as described previously, that is, common with the Type A robots. There are, however, some major differences in control systems and some unique physical features.

The significant features of the Type B robot are:

During programming and playback, data is sampled on a time base, rather than as discretely determined points in space. The sampling frequency is typically in the range of 60 to 80 Hz.

Due to the high rate of sampling of position data, many spatial positions must be stored in memory. A mass storage system, such as magnetic tape or magnetic disc is generally employed.

During playback, due to the hysteresis of the servo valves and inertia of the manipulator, there is no detectable change in speed from point-to-point. The result is a smooth continuous motion over a controlled path.

Depending upon the controller and data storage system employed, more than one program may be stored in memory and randomly accessed.

The usual programming method involves physically moving the end of the manipulator's arm through the desired path, with position data automatically sampled and recorded.

Speed of the manipulator during program execution can be varied from the speed at which it was moved during programming by playing back the data at a different rate than that used when recording.

Type B robots share the following characteristics:

These robots generally are of smaller size and lighter weight than point-to-point robots.

Higher end-of-arm speeds are possible than with point-to-point robots; however, load capacities are usually less than 10 kg (22 lbs.).

Their common applications are to spray painting and similar spraying operations, polishing, grinding and arc welding.

The programmable, non-servo robots, Type C and D also share some common characteristics between themselves and operate in the same basic manner. A typical operating sequence of a Type C or D hydraulic or pneumatic actuated robot is as follows:

Upon start of program execution, the sequencer/controller initiates signals to control valves on the manipulator's actuators.

The valves open, admitting air or oil to the actuators and the members begin to move.

The valves remain open and the members continue to move until physically restrained by contact with end stops.

Limit switches signal the end of travel to the controller which then commands the control valves to close.

The sequencer then indexes to the next step and the controller again outputs signals. These may again be to the control valves on the actuators or to an external device such as a gripper.

The process is repeated until the entire sequence of steps has been executed.

The significant features of a Type C or D robot are:

The manipulator's various members move until the limits of travel (end stops) are reached. Thus there are usually only two positions for each axis to assume.

The sequencer provides the capability for many motions in a program, but only to the end points of each axis.

Deceleration at the approach to the stops may be provided by valving or shock absorbers.

It is feasible to activate intermediate stops on some axes to provide more than two positions; however, there is a practical limit to the number of such stops which can be installed.

The programmed sequence can be conditionally modified through appropriate external sensors; however, this class of robots is restricted to the performance of single programs.

Programming is done by setting up the desired sequence of moves and by adjusting the end stops for each axis.

Common characteristics of non-servo robots include:

Relatively high speed may be possible, due to the generally smaller size of the manipulator and full flow of air or oil through the control valves.

Repeatability to within 0.25 mm (0.010 in.) is attainable on the larger units and to within 0.1 mm (0.004 in.) or better on smaller units.

These robots are relatively low in cost; simple to operate, program and maintain; and are highly reliable.

These robots have limited flexibility in terms of program capacity and positioning capability.

The differences between Type C and Type D robots are minimal, although the two types are not necessarily interchangeable in all applications. The Type D robots are generally constructed to mount directly onto a die casting or plastic molding machine and provide only as many axes of motion as are necessary to perform a single function, namely, to extract a part from the machine and drop it into a container or onto a conveyor. In many cases, a Type C robot could perform the same function as a Type D but might have more capability than was required for the task and might not, therefore, be as cost effective or as efficient.

There are hundreds of manufacturers of robots worldwide and their products provide a wide range of capabilities relative to performance, that is, load capacity, speed, positioning accuracy (repeatability), flexibility, etc. There is no "ideal" robot, capable of performing all tasks equally well. The user must, therefore, establish parameters of performance and choose the robot which best meets these requirements.

There are definite tradeoffs in performance capabilities, as with most mechanical devices. For example, robots capable of handling heavy loads usually do not move rapidly. In fact, load capacity specifications for robots often quote nominal full-speed payload capacity and maximum payload capacity, at reduced speed. The maximum payload capacity may be as much as 50% greater than nominal, at 30% to 50% lower speed.

Another area where performance tradeoffs are made is in positioning repeatability, which is often referred to, erroneously, as "accuracy". There are a number of factors which affect repeatability, including speed, load, drive system and positioning system. Some of these factors, in turn, trade off with other performance parameters.

The best positioning repeatability is attained by using physical stops to establish axes positions. This is the positioning system used on non-servo (Types C and D) robots. Such robots, however, lack the multi-position flexibility of the servo-controlled (Types A and B) robots.

The following table summarizes the significant trade offs:

TABLE 1. - TRADE OFFS IN ROBOT PERFORMANCE CAPABILITIES

Capability	Significant Trade Offs
Speed	Repeatability, load capacity, Size of work envelope
Repeatability	Speed, load capacity, Size of work envelope, Flexibility
Load Capacity	Repeatability, Speed
Size of Work Envelope	Repeatability, Speed
Flexibility	Low Cost, Simplicity
Reliability	Flexibility

An issue related to trade offs is that of the relative merits of general purpose and special purpose robots. Here again, the basic difficulty is that no "perfect" robot exists -- there is no robot which can perform all automobile manufacturing tasks well -- and trade offs must be made for many applications. Presently, the trend of the robotics industry is to develop special purpose robots for applications with a sufficiently large market (or potential market).

For the user, the availability of special purpose robots can be of significant advantage. Applications engineering is usually simpler and less costly than it would be if a general purpose robot were used. The reliability of the operation is generally higher because the major element of the system is a more-or-less "standard" robot. The efficiency of the operation is generally higher because the special purpose robot's capabilities are matched to the requirements of the task.

However, the user is giving up some flexibility; although the robot can be re-applied on a similar operation if the original task is discontinued, it cannot be used on a significantly different job. That is, a painting robot, for example, can be used to spray other materials, such as undercoating, but cannot be used for spot welding or material handling.

Presently, a number of examples of such special purpose robots exist in the automobile industry. These include robots for spraying, arc welding and small-component assembly. The following table summarizes the significant characteristics of each of these special purpose robots. For comparison, the significant characteristics of a typical general purpose robot used by the automobile industry are also shown:

TABLE 2. - UNIQUE CHARACTERISTICS OF SPECIAL PURPOSE ROBOTS IN AUTOMOBILE MANUFACTURING

Robot Purpose	Unique Characteristics
Spraying	Direct lead-through programming
	Continuous-path, trajectory control playback
	Light Payload (15 lbs.)
	Low inertia, high speed arm (60 in. per second or more)
	Large memory (up to 20 minutes)
	Intrinsically safe in explosive atmosphere
Arc Welding	Point-to-point programming
	Continuous-path, trajectory control playback
	Precise, low speed traverse rates (± 1% of programmed speed)
	Linear or circular interpolation
	Good positioning repeatability (± .010 in.)
	Up to seven axes of motion/control
Assembly	Anthropomorphic size and configuration
	High speed motions (50-60 inches per second)
	Good positioning repeatability (± .005 inches)
	Computer control
	Sensory feedback capability (vision, force, touch, etc.)
	Off-line programming, high-level programming language
General	Point-to-point programming, point-to-point playback
	Heavy payload (up to 250 lbs.)
	Any configuration (cartesian, cylindrical, polar or anthropomorphic)
	Limited memory (about 1000 points)
	Moderate repeatability (± .050 inch)
	Electronic control

There are a number of developments in industrial robots which are likely to evolve in the near future. Some of these will come from user development programs, some from robot manufacturers and some from independent research organizations. Regardless of the source, these developments will come in response to present or future requirements, which will be identified and described by the potential users, including the automobile industry.

One area of continued development will be an increasing number of special-purpose robots. These will include programmable devices for loading and unloading stamping presses, small high-speed assembly robots and medium-sized, electric drive assembly robots.

Devices presently used in the U.S. for loading and unloading stamping presses and for transferring stampings from press to press include point-to-point, servo-controlled (Type A) robots, point-to-point, non-servo (Type C) robots and non-programmable mechanical transfer (Type E) devices. The Type A robots are generally too costly for these applications and have marginal speed and positioning repeatability. Except for very small units capable of handling less than a one pound payload, the Type C robots are too slow for these applications. The Type E devices lack the manipulative capability required for some loading operations and also lack the flexibility to accommodate rapid changes.

Some relatively fast, simple Type C robots have been developed in Japan by Aida, Daido and Toshiba Seiki, primarily for press work. The speed and precision of these devices are impressive: handling of stampings up to four by eight feet in size, weighing 35 to 40 pounds on multiple-press lines at cycles as short as five seconds for transfer and press actuation is not uncommon. Comparable operations in U.S. stamping facilities are accomplished only with hard automation on

dedicated (single-product) press lines. These Japanese press-tending robots are generally pneumatically actuated and are priced in the low to mid $20,000 range. At this time, none of these robots are being marketed in the U.S. and only one is being distributed in Europe.

Another special purpose robot which would be applicable for automotive operations is a high-speed assembly robot. There are numerous small, servo-controlled, electric drive (Type A) "assembly" robots available in the U.S., Europe and Asia. These units have adequate positioning repeatability and most, being controlled by a microcomputer, have a high degree of flexibility, making them particularly adaptable for batch manufacturing. There are also numerous small, non-servo, high-speed (Type C) "pick-and-place" robots, useful for high volume production, available. These robots are so lacking in flexibility and capability, however, that it is common practice to dedicate each robot to the handling of a single part or the performance of a single step in an assembly operation.

For the relatively high production volumes common in the assembly of small components for automobiles, what is required is a robot capable of accurate movement and positioning at speeds two to three times as fast as the 20 to 30 inches per second characteristic of present Type A "assembly" robots. This new assembly robot should also be capable of executing several routines as part of its normal task and be easily programmed to compensate for minor changes in its operational environment or to perform new tasks.

The development of such a robot is within the scope of the current state-of-the-art and at least two approaches would be feasible. One approach would be the improvement of the power and stiffness of drives and mechanisms to produce high-speed movements with good positioning repeatability. The power and precision required in the mechanism would probably result in a significant increase in price compared to present

Type A "assembly" robots. Another approach would involve reduction of the mass of the mechanism to increase speed and automatic compensation for positioning inaccuracies likely to result from a lack of mechanical rigidity or repeatability. This would require new software, increased control capability, initialization or "zeroing" routines and, perhaps, higher resolution position feedback devices.

A third special purpose robot is a medium sized, servo-controlled (Type A) robot for assembly. The "assembly" robots presently available are mostly relatively small devices having typically, a spherical working volume of less than 36 inches radius and a payload capacity (part plus end-effector) of less than 10 pounds. A few slightly larger robots, including the ASEA IRb6 and Hitachi Process Robot are available, but these are significantly more costly than the smaller units (up to $60,000 or more) and also are marginal in payload capacity (about 20 pounds maximum).

There are significant numbers of, primarily, mechanical assembly operations, which require the larger work envelope and higher payload capacity of this new medium sized assembly robot. These include the assembly of heads, blocks and engines, transmissions, differential units, suspension systems, steering gear and columns, brakes, air conditioning compressors, etc. The new medium sized robot capable of performing these tasks should be electrically driven and servo-controlled (Type A), with a payload capacity of 25 pounds to 50 pounds and a work envelope having a radius of at least 42 inches. It should be micro-computer controlled, with a good positioning repeatability (± .005 inches) and should move at speeds up to 50 inches per second. The cost should be around $50,000.

The development of the foregoing new robots will, at least in the U.S., come from manufacturers and distributors of robots. The prospective users (that is, the automobile industry) may, however, have significant input in the form of performance specifications and perhaps shared funding for new product development.

Another likely area of robotic development will be in control and monitoring, particularly hierarchical systems involving numbers of robots performing a common task. A current example of this is General Motors' NC Painter, which uses a hierarchy of computers to control as many as 10 robots, allocating programs to each, monitoring performance and reallocating programs whenever a robot is down for any reason. Other robotics applications where centralized control and monitoring are applicable include spot welding, transfer machine loading and unloading and assembly.

In spot welding operations, it is common practice to install a number of robots, perhaps as many as twenty, along with a transfer and positioning system to move and orient the sheet metal assemblies being welded. At present, if any of the robots is unable to perform its welding tasks, due to malfunction of it or of its welding equipment, the missed welds are made either manually or with a "standby" robot at the end of the transfer system. Activation of the "standby" robot and selection of the welding program it is to execute is generally done manually.

With a centralized control and monitoring computer, the activation of the "standby" robot could be automatic. Alternatively, a more effective approach would be for the central computer, upon detection of a robot or welding equipment malfunction, to redistribute that robot's task among the remaining robots on the line, thereby eliminating the need for "standby" robots. In most cases, this could be accomplished without delay and without significant impact upon the normal cycle time

of the system. The monitor could also shut down a robot for periodic maintenance (particularly of the welding gun) to assure quality welds and prevent breakdowns, according to a predetermined schedule or whenever there were indications of declining weld quality.

Similarly, in transfer machine loading and unloading, the centralized computer could direct the robots under its control to transfer parts to or from storage buffers or between parallel machine lines. In this way, it would maintain relatively constant output despite interruptions on various segments of the system.

In assembly operations, the central computer could monitor and direct the robots under its control in a manner similar to the transfer machine systems. In addition, for batch assembly operations, the centralized control could down-load new programs for the robots whenever there was a change in the product being assembled.

The basic programs and interconnections for such hierarchical computer systems for robot monitoring and control are and will continue to be formulated by basic research and development organizations. Much of the necessary hardware and software already exists or has been described. However, implementation of these techniques will be accomplished by the user or by the supplier of the total system. It is unlikely that the robot manufacturers and distributors, unless they are also in the systems business, will contribute significantly to these developments.

Another development area, one where there is presently a great deal of activity, is that of sensory feedback for robots. The industrial robots currently in use in automobile manufacturing and assembly operations are "deaf, dumb and blind" and perform their task entirely by rote. Thus, a repeatable, orderly environment is necessary, one which requires

mechanisms to transfer, orient and position the work for the robot. This is often in complete contrast to the work handling methods which are provided for manual performance of the same tasks.

Sensory systems under development include vision, tactile and force sensing, with the systems including the sensors, electronic interfaces with the robot controls and robot controller software. Much additional development is needed on all three elements of the systems.

Of the three most common types of robot sensory feedback systems, vision, tactile and force, the vision capability seems to offer the greatest potential flexibility for robot applications. In the automotive field, robot vision could be used effectively for a wide variety of applications, including spot welding, arc welding, assembly, machine tending, inspection and general material handling. Robot vision is, in fact, considered a key element in the successful implementation of most arc welding and assembly operations and in some machine tending and material handling operations as well. Vision systems are also the most complex to develop and implement.

Present vision systems require special lighting and/or movement of parts, special electronic interfaces between camera and data processor and relatively long data processing time. They lack depth or range perception or good image resolution. The vision systems which are commercially available or being developed are very robot-specific; that is, they work with only certain models of robots. Image data processing time, the time required for the system's electronics to extract useful information from the "picture" the vision system sees and transmit appropriate data and commands to the robot controller, is generally so long that real-time control of the robot's movements are not feasible.

Further development is required in all elements of robot vision systems. Resolution, light intensity limits, gray scale and color discrimination capabilities of solid-state imaging devices (cameras) need improvement. New and modified data extraction, data processing and image reconstruction algorithms and methods must be devised to increase the speed of the systems. Real-time, high-speed interfaces with the robot controls need to be developed to permit control of a robot's movements with external feedback devices at normal operating speeds. System hardware and software must be made less equipment-specific so that any vision system can work with any robot.

Force feedback is another sensory system requiring significant development. As with vision, force feedback systems today exist primarily in laboratories and research facilities. Such systems will be useful in assembly, machine tending, foundry, deburring and polishing operations.

Developments required include rugged, simple force sensors with good sensitivity over a wide force range and real-time, high-speed interfaces with robot controls. Force feedback systems should be capable of being easily programmed to control the magnitude and direction of a force exerted by the robot arm, under varying conditions.

Tactile sensors may be somewhat simpler to develop and implement; some rudimentary tactile sensing is already being used for removing parts or material from racks or stacks. In this area of sensory feedback, development is now centered upon sensor arrays capable of extracting shape information from contact with a part. Such capability could enhance robot applications to machine tending, assembly and material handling operations through determination of part position and orientation while the part was being handled. As with other sensory feedback systems, further development of sensors is required, as well as

real-time, high-speed interfaces with robot controls. In the U.S., the development of sensory feedback systems is presently concentrated primarily in basic research organizations, with limited activity also in user research facilities and among some robot, electronics and sensor manufacturers. Because all of these sensory feedback systems require the integration of several technologies and combinations of various commercial and special components, it is not likely that either users or robot manufacturers will take over the basic research and development or the commercialization of such systems. In the near future, it is probable that sensor manufacturers will develop and market "plug-in" sensory feedback systems for robots, using the results of the continued development efforts of the basic research organizations.

The situation in Europe and Japan is somewhat different. There, fundamental developments in sensory feedback technology are undertaken in basic research organizations, but the application of these fundamentals, that is, the development of sensory systems, is primarily handled by the manufacturers of robots (who, incidently may also be the major users of these robots). Thus, the integration of robots and sensory feedback may evolve more quickly. On the other hand, the development of more universal, "plug-in" sensory feedback systems is less likely under this condition.

An important area of future development will be the integration of robotics into computer-aided design/computer-aided manufacturing (CAD/CAM) systems. One of the first steps in this integration process will be the development of off-line programming for robots, that is, the preparation of sets of instructions for robots at a computer terminal, using a vocabulary of commands. Off-line programming vocabularies or "languages" have already been developed by the robot manufacturers or by basic research organizations for a few specific robots. However, each language is different from the others and none are compatible with existing CAD/CAM system languages.

The integration of robotics with CAD/CAM, therefore, will require the development of translation programs, which will be equipment-specific (much like the post-processor programs for NC machines). These programs will take a set of general instructions for a robot task, developed with a CAD or CAM computer, and convert them into specific commands for a specific robot in a particular location in the factory. The advantage of this approach is that robot programmers will not have to learn a whole series of languages, one for each kind of robot.

There are several significant benefits to be gained from off-line programming of robots. In robotic painting applications for example, the robots are currently programmed by guiding the robot through the desired motions, on location in the paint booth. This requires a skilled spray painter who has also been instructed in robot programming. It also necessitates either interrupting production or programming on weekends or during the night after production has been stopped. Programming of other robot tasks such as machine tending, spot welding, assembly, etc. also must be done on location. Where the robot's tasks are complex, as in spot welding or assembly, the programming on-site can take a great deal of time. Simulation or tryout cannot be accomplished without actually installing the robots in the work place or constructing a detailed mockup of the work place. Off-line programming and integration with CAD/CAM systems will largely overcome these problems.

The development of off-line programming capabilities will be undertaken primarily by the manufacturers of robots. This will not, however, resolve the problem of equipment-specific languages or facilitate the integration of robotics with CAD/CAM. The development of translation and simulation programs and integration with CAD/CAM will thus be done primarily by manufacturers of CAD/CAM computers and systems, by major robot users, or by third party systems contractors.

Another important development area is the establishment of "standards" for industrial robots. Such standards will include mechanical interfaces for mounting end-of-arm devices on the robots, electrical interfaces for interconnections between the robot controller and the external devices with which the robot interacts, sensor interfaces for sensory feedback systems and computer interfaces for hierarchical control systems, monitoring and off-line programming. Other standards will include the programming languages themselves, performance evaluation, testing and reporting of results and terminology used to describe the robots, their configurations, their components and their performance.

The National Bureau of Standards has already sponsored a work shop on robotic standards and is funding the development of a glossary of robot terminology. It is likely that NBS will continue in its leadership role in this development area, although actual standards will probably be developed, reviewed and published by committees made up of robot users, manufacturers and NBS representatives.

In Europe and Japan, some standardization development is already underway. A government supported research organization in West Germany is involved in the systematic testing and evaluation of robots, according to standard procedures which they developed. Results of tests on a number of robots have already been published. The Japan Industrial Robot Association has developed and published a glossary of terms and is developing evaluation and testing standards and performance specifications standards.

The following table summarizes some of the current and potential application areas for robots in automobile manufacturing and the related developments which are either necessary or highly desirable to enhance these applications.

TABLE 3. - FUTURE DEVELOPMENTS IN ROBOTS AND ASSOCIATED EQUIPMENT TO ENHANCE AUTOMOBILE MANUFACTURERING OPERATIONS

Application	Development
Metal Forming	Special purpose robot - high speed Type C, medium to large size, low cost
Spot Welding	Sensory feedback system - simple vision
	Computer control and monitoring for multiple-robot systems
	Computer aided design - off-line programming
	Standardized mechanical, electrical and computer interfaces
Arc Welding	Sensory feedback system - vision based joint tracking
Component Manufacturing	Sensory feedback systems - simple vision, force feedback, tactile
	Computer aided design - off-line programming
	Computer control and monitoring for multiple-robot/machine systems
	Standardized mechanical, electrical and computer interfaces
Assembly	Special purpose robots - small high speed Type A, medium sized Type A
	Sensory feedback systems - vision, force feedback, tactile
	Computer aided design - off-line programming
	Computer control and monitoring for multiple-robot systems
	Standardized mechanical, electrical and computer interfaces
Painting	Computer aided design - off-line programming
	Computer control and monitoring of multiple-robot systems
Inspection	Sensory feedback systems - vision, force feedback, tactile
	Computer aided design - off-line programming
	Computer control and monitoring
Material Handling	Sensory feedback systems - vision, tactile
	Standardized mechanical and electrical interfaces

Although a number of basic requirements have been identified, robotics development and limitations on it must be considered from a number of aspects. In the development area, both basic research and applications development are important. Equally important are those factors which either encourage or inhibit implementation, such as research and development, engineering support, experience and education. In all of these aspects, the United States, once a leader, appears to be losing ground to the Europeans and the Japanese, based upon the respective levels of effort in robotics development.

Although there is basic robotics research going on at more than two dozen colleges, universities and research organizations in the U.S., the programs are small, poorly funded and understaffed and largely uncoordinated. Some applications development and associated research is also carried out at research organizations and at laboratories in a few corporations such as General Motors, General Electric, Caterpillar and Westinghouse. Basic applications development is also underway in the aircraft/aerospace industry, largely as a part of the Air Force's Integrated Computer Aided Manufacturing (ICAM) Program. Although the technology developed in the ICAM Program is supposed to be generic and transferable, little of the development to date will have direct application to the automobile industry.

The National Science Foundation (NSF) funds several on-going programs, including a robot vision for randomly oriented parts ("Bin Picking") program at the University of Rhode Island (URI). Funding for this research has totalled $570 thousand over the last six years. URI is now seeking an additional $1.5 million from industry for a three year extension of this program. The Stanford Research Institute (SRI) has also been funded by NSF at a similar level for a like period for basic research in the area of Machine Intelligence. Like URI, SRI has sought industry funds for continued research in this area and for other special development programs involving sensory feedback systems for robots.

A joint development program involving Unimation, Inc., Hamilton Standard of United Technologies Corporation and Jet Propulsion Laboratory has recently been announced. The program involves the adaptation of infrared (laser) sensors for range sensing for robots and may be applicable for spot welding of car bodies on moving conveyor lines without precise orientation of the bodies. Funding amounts to $500 thousand and was provided by NASA and industry. The program is being coordinated by a joint NASA and Illinois Institute of Technology Research Institute (IITRI) organization, the NASA/IITRI Manufacturing Applications Team (MATeam).

The National Bureau of Standards (NBS) has had a modest robotics research effort underway for a number of years. The program is concentrating on sensory feedback systems (primarily vision) and control computer architecture for real-time robot servo-control from external sensors. NBS also has a machining cell with a robot being set up as part of a computer aided manufacturing development program.

In contrast to these limited (although significant) public and private development programs in the U.S., are manufacturing technology and robotics programs in Europe and Japan. Basic robotics research in Japan is being carried out in 85 laboratories in universities and public research institutions which are now working on 64 research projects. Funding for these programs is in excess of $1.5 million annually, not including salaries, wages and indirect expenses for the 350 researchers involved. The Ministry of International Trade and Industry (MITI) has recently announced a seven year, $150 million national robot research program which will begin April 1, 1982. MITI will create a new R&D group to carryout the program, which is called a "nationally important, major technology development scheme". Emphasis will be placed on intelligent robots, especially for assembly work and on robots for nuclear, space and underseas applications. The development of sensory feedback systems, programming languages and mobility will receive high priority.

The Japan Industrial Robot Association (JIRA) is also active in the administration of research programs, primarily in applications areas, such as automated systems for disposing of chips in machining processes, basic specifications of modular robots, automated system for deburring of cast iron, system design for computer aided robot system engineering and cooperation in the national project "Flexible Manufacturing System Complex with Laser". JIRA is also involved in activity to promote the development of application technology of industrial robots, administering a fund of about $3 million for this purpose.

There are also a number of long-term cooperative research programs done under government sponsorship with cooperation between specialists in the academic and industrial fields. Among these are: Industrial Robot Standardization Research Project (1974-1978); Computer Aided Robot Engineering Research Project (1976-); Pattern Information Processing Research Project (1971-1980); Casting Deburring Robotization Research Project (1975-1976, 1978-1983); Laser Applied Complex Production System Research Project (1977-1983); and Assembly Robotization Research Project (1976-1978).

There are about 140 companies manufacturing robots in Japan, including many of the largest industrial firms in the country. A number of these companies produce robots primarily for use in their own operations. The expenditures of these private enterprises on robotics development have never been announced but are estimated to far exceed the public funding. Of 107 robot manufacturers surveyed by JIRA in 1979, twenty had a specialized robot research division in their in-house research laboratories and another 52 without a special robot research division had one or more researchers specializing in basic robotic research.

In West Germany, government and industry support manufacturing technology development (which includes robotics as a significant part) at an estimated $100 million annually. The Federal Ministry for Research and Technology (BMFT) sponsors a number of programs, including "Humanization of Working Conditions", with involvement in production and manufacturing areas and robotics; development and application of manipulators, automatic handling machines and handling systems; and a new "Advanced Manufacturing Technology" program which will encompass the maintenance and increase of the competitiveness of both equipment and user companies in manufacturing technology, safety of work sites, savings of raw material and energy, reduction of environmental stresses, improvement of working conditions and the development of new handling systems. The BMFT also funds the Association for Fundamental Technology (GFK) which is involved in development programs in computer aided design and process control by computer, and the German Institute for Aerospace Research and Experimentation (DFVLR) which coordinates and monitors "Humanization of Working Conditions" and "Advanced Manufacturing Technology" programs, as well as developing sensors and feedback systems for robots.

German Research Society (DFG) supports research on machine tools and controls, robotics, production systems, production engineering and manufacturing technology at the Technical Universities of Aachen, Berlin and Stuttgart. About $30 million a year is provided for these programs, half from the federal government and half from the States. Other government agencies, as well as industry, also contribute to these programs. The Association of Industrial Research Groups (AIF) is an organization that supervises the members' interests in the field of industrial research. The AIF has a budget of $100 million, which is closely matched by members' funding for individual research projects. The Fraunhofer Foundation (FhG) is an organization of institutes for applied research which performs contract research work. Two of the organization's members, the Institute for Production and Automation (IPA), Stuttgart, and the Institute for Data Processing in Technology and Biology (IITB) Karlsruhe, are current involved in industrial robot developments.

In France, the Association Francaise de Robotique Industrielle (AFRI) was founded in 1977. Within two years, it was comprised of 15 industrial groups and 8 research organizations, including both national and private research laboratories. The principle areas of research are visual and tactile pattern recognition, integrated control of robots and development of end-effectors.

The French automobile manufacturer, Renault, is deeply involved in basic robotics and in application development. Renault invested more than $15 million in a six year robot development program and continues to spend more than $2 million a year on robot research and development. Renault robot technology is considered some of the most advanced available and its ongoing R&D effort is one of the largest underway in the world.

In the United Kingdom, aside from development activities at various robot manufacturers, the major research activities are undertaken either by the government's National Engineering Laboratory (NEL) and Harwell Research Station or by academic institutions. Twelve institutions are presently involved with projects related to industrial robots. Nottingham University and Hull University are engaged in projects ranging from vision systems to computer graphics simulation of robot systems. Surrey University is working on a pneumatic powered robot and micro-processor controls. Visual feedback and computer control of robots is being investigated at Aberystwyth University. Warwick University is working on mobile robots, tactile sensors, micro-processor controls and software.

The development of ultrasonic sensors for industrial robots is being investigated at Keele University University College, London has developed a robust, low-cost, 3-axis manipulator and research is continuing into digital control techniques needed for interaction of the manipulator with moving objects. Manipulator dynamics are also being studied at Newcastle University and Wolverhampton Polytechnic. Edinburgh University is involved

in major computer software development, directed towards languages for instructing assembly robots. Queen Mary College, London, is working on computer software for control of mobile robots and for vision systems using digital array processors.

In the area of robot applications, the development of computer control for arc welding with robots is being actively pursued at NEL. The application to small batch welding is currently under investigation. At Birmingham University, a feasibility study into the robot fettling (grinding) of castings has been completed and research on the automatic detection and handling of faulty parts is being performed.

In Sweden, institutional research on industrial robots is less concerned with the development of the robot itself than with its application and integration into different production situations and systems. Research is carried out by the Swedish Institute of Production Engineering Research (IVF), Stockholm and by the universities of Lulea and Linkoping.

IVF is involved in a general study of partly manned production, where robots are essential for continuous operation. The University of Lulea is investigating the physical, mental and social effects of robots on human labor. The University of Linkoping is working on three main problem areas of automated production systems: computer-aided process planning, process supervision and machine condition monitoring and transport and handling of parts. Industrial robots are an alternative being investigated in the latter problem area, with development underway in end-effectors, adaptive control (vision and tactile sensing) and interaction between robots and other machine units.

A commission appointed by Sweden's Ministry of Industry is investigating the effect of the use of advanced electronics, including computers, in production equipment. Part of this investigation concerns the future impact of robot technology. The commission is considering whether and in

what form measures shall be taken by the government either to stimulate a greater and more effective use of this technology or to improve the means for predicting and preparing the changes that may be necessary.

In Italy, robotics research is carried out in universities, in special research centers and in industry, with very little government aid. The Institute of Electro-Technics and Electronics, Polytechnic School, Milan, is involved in a number of studies, including stepping motor performance in a robot, multi-microcomputer structure, programming language, object recognition and programming of assembly problems. The Institute of Mechanics and Machine Constructing, Polytechnic School, Milan, is studying a flexible gripping device, microcomputer control, force sensors and stepping motor actuators.

The Laboratory of Mechanical Technologies, CNR-CEMU, Cinisello Balsamo, is studying rotary joint actuation with stepping motors and a programming system for a special robot. The Laboratory of System Dynamics and Biological Electronics, CNR-LADSEB, Padua, is studying algorithms for microcomputer control of mechanical members. The Laboratory of Numerical Analysis of Signals, CNR-LAMS, Turin, and the Institute of Science of Information, University of Turin, are working on voice control/programming of robots.

The Institute of Electro-Technics, University of Genoa, is studying anthropomorphic models and object recognition. The institute of Machine-Applied Mechanics, University of Genoa, is studying the theoretical aspects of identification and optimization of kinematic models of robot structures. The Institute of Machine Technology and Design, Bologna, is studying a mechanical hand provided with a movable and adjustable grip. The Institute of Automatics, University of Rome, is studying mathematical models of an articulated arm to define control parameters and the control structure of a six-legged robot for exploration of rough land.

In industry, little of the research and development work has been publicized. An exception to this is Olivetti, which manufactures relatively small, high capability robots for assembly. Olivetti's SIGMA robot has vision system capability and adaptive force feedback for close tolerance component insertions. A computer language has also been developed for off-line programming.

The foregoing descriptions of worldwide robotics research and development efforts and accomplishments would indicate that basic knowledge is not a limitation on robotic applications. As described previously, however, practical, affordable, reliable software and hardware still needs to be developed from this basic knowledge. In addition, incentives may be needed to encourage the implementation of advanced technology robotics or, indeed, to encourage the implementation of robotics in any form.

Such incentives are already in evidence in France, the United Kingdom and in Japan. In March, 1981, the French government announced the award of $50 million in aid for investment in robotics by French industry. This program, involving loans under the government's plan for the development of strategic industries, will be distributed over the next 15 months for 10 different projects.

In the United Kingdom, the Production Engineering Research Association (PERA) has, since January, 1980, been offering a low-cost advisory service to industry in the area of robot application. PERA's Robot Advisory Service (RAS) conducts briefings for top management, operates a robot demonstration center and makes free visits to firms to help management decide if there is justification for installing robots. Following this initial assessment, PERA will provide up to 15 man-days of advisory project work on a 50% cost basis. The advisory project work includes a study of the company's work handling and materials flow problems as well as the robot's tasks. Recommendations are also made regarding the robots

most suitable for the tasks and a preliminary design for an end-effector may be provided. PERA is also installing, at its facility, an interactive graphics system (developed at Nottingham University) for robot simulation, to further facilitate its advisory service.

In Japan, a robot leasing company, Japan Robot Lease (JAROL) was founded in April, 1980. The aim of JAROL is to support robot installation by small and medium-sized manufacturers and increase their productivity. Because 60% of its operating funds are financed by low cost loans from the government's Japan Development Bank, JAROL's terms are more advantageous than the ordinary leasing companies. In its first year of operation (fiscal year 1980) JAROL completed 52 leasing contracts amounting to about $57.5 million. JAROL also now offers a more flexible 2-3 year rental agreement.

Other incentives arranged by MITI include direct government low-interest loans to small and medium-sized manufacturers to encourage robot installation for automating processes dangerous to human labor and for increasing productivity. For fiscal year 1980, the government budgeted more than $25 million. MITI also permits the manufacturer who installs a robot to depreciate 12.5% of its initial purchase price in the first year in addition to taking ordinary depreciation. By installing an industrial robot, a firm can depreciate 52.5% in the first year, 12.5% plus 40% (5-year depreciation double declining).

Except for components described previously, that is, sensors, interfaces, etc., there are no foreseeable problems with component availability. Accelerated usage of robots may cause delays in delivery due to lagging growth of production capacity, but this should be only a temporary situtation. Availability of knowledgeable, experienced personnel to identify, engineer and implement robot applications is more critical. It is already a problem, one which will become more severe during the next few years.

The problem is particularly acute in the North American automobile industry. In the face of rising costs and declining sales, the industry has reduced its professional staffs, particularly in the less critical areas such as manufacturing engineering and research and development. Typically, advanced manufacturing technology programs are curtailed or cancelled during such periods of economic stress. Personnel who had been involved in industrial robot programs often found that their expertise was no longer required; the robot implementation programs were cut back, delayed or cancelled and they were either reassigned, retired or laid off or they quit. Concurrently, the use of robots in other industries continued to grow and these personnel found their qualifications in demand outside of the automobile industry.

As a result, the automobile industry now faces a shortage of experienced personnel to implement new robotics programs. Formal education programs to train robotics application engineers are virtually non-existent and the products of such programs, if they were available, would still need several years of practical experience before they became effective. In-house programs to develop the necessary expertise are also virtually non-existent and, again, such "trainees" will need experience in addition to the training. Some limited assistance is available from the manufacturers and distributors of robots and from independent robotic systems engineering firms. However, these resources will be totally inadequate to support large scale robot implementation programs in the North American automobile industry.

ROBOT IMPLEMENTATION

There is a wide variety of robots available to the U.S. automobile industry. Prices, capabilities and applications also vary widely, as shown:

TABLE 4. - ROBOTS CURRENTLY AVAILABLE TO THE U.S. AUTOMOBILE INDUSTRY

TYPE	SUPPLIER	PRODUCT	PRICE RANGE ($000's)	AUTOMOTIVE APPLICATIONS
A	Armax	Armax	85-100	Spot welding, grinding
A	ASEA	IRb6	60-62	Arc welding, polishing, deburring, assembly, inspection
		IRb60	88-100	Spot welding, grinding, machine loading
A	Bra-Con Industries	Rob-Con Pacer	45-95	Press loading, plastic molding, spot welding
A	Cincinnati-Milacron	T3	75	Spot welding, arc welding, machine loading, inspection
A	Cybotech	Type 80	150	Spot welding, arc welding, machine loading
		Type 8	50-60	Light assembly
A	General Elec.	Allegro	NA	Light assembly
A	General Numeric	GN0,GN1, GN3	40-70	Machine loading
A	KUKA	IR 601/60	120-130	Spot welding
A	Prab Robots	Versatran	45-100	Spot welding, machine loading, Press loading
A	Reis	Reis Robot	60-90	Machine loading, material handling
A	Thermwood	Series Three	30-60	Machine loading, material handling, arc welding
A	Unimation	1000	25-35	Die casting, machine loading
		2000	45-65	Machine loading, spot welding, material handling
		4000	65-85	Spot welding, machine loading, material handling
		PUMA	45-50	Light assembly
A	U.S. Robots	Maker	40-50	Light assembly

TYPE	SUPPLIER	PRODUCT	PRICE RANGE ($000's)	AUTOMOTIVE APPLICATIONS
B	Automatix	Hitachi	85	Arc welding, inspection
B	Binks	88-800	50-55	Spray painting
B	Cybotech	Painter	130	Spray painting
B	DeVilbiss	Trallfa	90-100	Spray painting
B	Graco Robotic	OM 5000	120	Spray painting
B	Hobart Brothers	Yaskawa Motoman	90	Arc welding
B	Nordson	Nordson	85-95	Spray painting
B	Shin Meiwa	PW150,PW751	80-130	Arc welding
C	Armax	Armax	40-50	Die casting, material handling, machine loading
C	ASEA	Electrolux MHU	25-40	Material handling, machine loading
C	Copperweld Robotics	AP10,AP50	15-25	Material handling, light assembly, machine loading
C	Industrial Automates	Automate	15	Material handling
C	Manca/Leitz	Manta	15-45	Material handling, machine loading
C	Mobot	Mobot	15-45	Material handling, machine loading
C	Prab Robots	Prab	25-35	Die casting, plastic molding, machine loading, material handling
C	Seiko	Model 100, 200,400,700	7-15	Material handling, light assembly
D	ISI		2-10	Press loading, machine loading
D	Livernois Automation		5-20	Press loading, machine loading
D	Sterling Detroit		20-40	Die casting, plastic molding
D	Rimrock		15-25	Die casting, plastic molding

For certain applications, the type of robot which is suitable limits the users' choices and the price is fairly constant, regardless of the robot supplier. For example, spot welding (the largest single automotive application) requires a medium to large sized Type A robot and the price range for such units is about $75 thousand to $150 thousand. Spray painting requires a Type B robot with a price of $55 thousand to $130 thousand.

Within and between these classes of application and robot, the higher price reflects higher capability. Types C and D robots, which cost significantly less than Type A robots, for instance, do not have the capabilities to perform spot welding operations or to load and unload machining lines where multiple machines and buffer storage systems may be involved. On the other hand, although a Type A robot could unload a die casting machine, a Type C or D robot could also perform such a task, at a much smaller initial investment.

The total investment in a typical robot installation in the automobile industry will be from two to four times the actual robot cost, depending upon the application. In major body assembly (spot welding) systems, the cost of fixturing, welding equipment and transfer or material handling equipment will often be at least three to four times the cost of the robots. That is, a system incorporating $500,000 worth of robots may cost, in total $1,500,000 to $2,000,000. In other robot applications, which tend toward one or two robots per installation, as typified by sub-assembly welding, machine tool loading/unloading and material handling, the total investment is generally in the range of twice the robot cost.

Table 5 shows, for a typical major body assembly system, the sources and relative magnitude of the cost elements of the system.

TABLE 5. - COST ELEMENTS OF TYPICAL MAJOR ROBOT SYSTEM FOR BODY ASSEMBLY

Element	Representative Cost ($000's)	Percent of Total System Cost
Twelve Type A Robots	850	34
System design	250	10
Welding guns, transformers and controls	150	6
Conveyors and/or transfer mechanisms	150	6
Locating and positioning fixturing	250	10
Controls and interfacing	200	8
Safety devices, guard rails, etc.	50	2
Site preparation	150	6
System assembly, tryout and shipping	250	10
System installation, robot programming and debugging	100	4
Personnel training	25	1
Efficiency and production losses during start-up	75	3
TOTAL	$2,500	100%

The sources and relative magnitude of the cost elements for a simple, one-robot installation applied to load and unloading two machine tools are shown in Table 6:

TABLE 6. - COST ELEMENTS OF TYPICAL SINGLE ROBOT INSTALLATION FOR MACHINE TENDING

Element	Representative Cost ($000's)	Percent of Total System Cost
One Type A Robot	55	44
System design	10	8
End-of-arm tooling	5	4
Conveyors and part orienters	15	12
Controls and interfacing	7	6
Safety devices, guard rails, etc.	5	4
Rearrangements and site preparation	5	4
Equipment relocation and revision	5	4
System installation, robot programming and debugging	5	4
Personnel training	3	2
Efficiency and production losses during start-up	10	8
TOTAL	$125	100%

The use of robots in automobile manufacturing operations incurs costs beyond the initial investment in the robot system. Like any machine, the robot requires periodic maintenance and is subject to occasional breakdowns, necessitating repair and/or replacement of components. The cost of robot maintenance and repair will vary widely, depending upon the type of robot, severity of the task and level of maintenance provided. For cost analysis and budget purposes, one major automobile manufacturer has developed some standards, based upon actual experience.

Using the recent maintenance records from one of its assembly plants which is operating 27 Type A robots of several brands, the cost of replacement parts and consumable supplies (hydraulic fluid, lubricants, filters, etc.,) was determined. Averaged over the number of robots and production shifts, a standard of $4.41 per 8-hour shift was established. This is about $0.55 per operating hour for maintenance and repair materials only. Incidently, this new (June, 1981) standard was a significant reduction from the $5.69 per 8-hour shift or $0.71 per operating hour standard which had been previously established in 1973.

In addition to the maintenance and repair material standard, there is a labor allowance for maintenance. This same major automobile manufacturer has established a standard of 1.698 hours per day per robot, operating on two production shifts and 1.029 hours per day per robot, operating on one production shift. Using a current indirect or maintenance labor rate of about $19.05 per hour (including fringe and related costs), this standard amounts to about $2.16 per operating hour. When the labor cost is added to the maintenance and repair material allowance, the total maintenance cost is about $2.71 per operating hour for Type A robots.

The costs for Type B robots would be about the same; this automobile manufacturer uses the same allowances for all servo-controlled robots. Maintenance and repair costs for Type C and Type D robots would be significantly less--on the order of $0.50 per hour--due to their simplicity

and the much lower cost of control and feedback components. A representative hourly maintenance and repair cost for Types A and B robots would be about 0.004 percent of the initial cost of the robot. In Types C and D robots, this representative cost would be about 0.002 percent of the initial cost of the robot.

Operating costs for a robot, in addition to maintenance and repair are primarily those related to "consumables" required by the robot to perform its task. These would include electrical energy or compressed air to power the robot and its control and, perhaps, compressed air to actuate a gripper or tool and, for some installations, water for cooling of hydraulic fluid and/or the control console.

In many applications, these "consumable" requirements are partially or completely offset by reduced requirements for lighting, heating, cooling or ventilation formerly needed by the human worker and, perhaps, reduced energy consumption by the process or machine serviced by the robot as a result of the robot's higher efficiency and productivity.

Other operation costs include amortization of investment, taxes, insurance, etc.

Unimation Inc. uses an hourly operation cost for their robots (which are servo-controlled, Type A) of about $5.00 per operating hour. This cost includes maintenance, as well as operation, and is based upon an average robot purchase price of about $60,000. Cincinnati Milacron uses a cost of $6.00 per operating hour, which reflects the somewhat higher average cost of their robot (compared to a Unimate). A representative total hourly operation cost, including all of the elements described above, would be about 0.008 percent of the initial cost of the robot for Types A and B. For Types C and D robots, the total hourly operation cost would be about 0.005 percent of the initial robot cost.

PRESENT STATUS OF ROBOTS IN WORLDWIDE AUTOMOBILE MANUFACTURING

At present, North America, Asia and Western Europe are the three major automobile manufacturing regions. Each of these geographical areas produces roughly the same quantity of automobiles, as indicated in Table 7, which shows world passenger car production for 1980. During the first three months of 1981, U.S. and Western Europe automobile production declined somewhat, compared to the first quarter of 1980, while Japanese production increased slightly, bringing regional production even more into balance.

TABLE 7. - 1980 WORLD PASSENGER CAR PRODUCTION AND ASSEMBLY-SELECTED COUNTRIES

Region	Country		1980 Production
North America	United States		6,373,071
	Canada		844,973
		Sub Total	7,218,044
Western Europe	West Germany		3,306,031
	France		2,714,466
	Italy		1,329,079
	United Kingdom		924,100
	Belgium		676,920
	Spain		953,988
	Sweden		197,248
		Sub Total	10,101,832
Asia	Japan		7,038,108
South America	Argentina		172,867
		GRAND TOTAL	24,530,851

TABLE 7. (continued)

Sources: Ward's Statistical Department from various world sources. In some of the lower volume countries for 1980 the 12-month totals are estimates based on 10- and 11-month actual counts. (Ward's Auto World, March, 1981)

The availability of technology and extent of utilization is also distributed fairly uniformly within each of these geographical areas. That is, technology in West Germany, for example, is quite similar to that in France and Italy, but not necessarily similar to that in Japan or the U.S. It is convenient, therefore, to compare geographical areas when establishing some overall positions relative to utilization of automation and industrial robots.

Table 8 shows the estimated population of industrial robots at year-end 1980 in fifteen countries in Asia, North America, Western Europe and Eastern Europe.

TABLE 8 - ESTIMATED INDUSTRIAL ROBOT POPULATION AT YEAR-END 1980

Region	Country	Robot Population by Type a/ A	B	C	D	E	Total
North America	United States	2485	439	1377	*	*	4,301
	Canada	54	5	10	*	*	69
						S/T	4,370
West Europe	West German	440	293	200	200	5000	6,133
	Sweden	720	180	300	*	*	1,200
	Italy	300	50	100	50	*	500
	France	320	60	150	*	*	530
	Norway	20	20	100	30	30	200
	United Kingdom	146	117	54	54	*	371
	Finland	20	10	70	10	20	130
	Belgium	42		82	3	7	134
	Spain	29	*	*	*	*	29
						S/T	9,227
East Europe	Poland	70	40	200	50	360	720
	USSR	100	50	200	150	2000	2,500
						S/T	3,220
Asia	Japan	5150		12050		50510	67,710
	Australia	14	*	*	*	*	14
						S/T	67,724

*Data Unavailable

GRAND TOTAL 84,541

a/ Type A: Programmable, Servo-Controlled, Point-to-Point
Type B: Programmable, Servo-Controlled, Continuous-Path
Type C: Programmable, Non-Servo, General-Purpose
Type D: Programmable, Non-Servo, Special-Purpose for Die Casting and Plastic Molding Machines
Type E: Non-Programmable, Mechanical Transfer Devices

Sources: Robot Institute of America, March, 1980, Daiwa Securities America Inc., July, 1981 and others

Although all of the robot types shown in Table 8 are used by automobile manufacturers or their suppliers, only the programmable devices (Types A, B, C and D) are of significance as indicators of the extent and level of automation technology utilization. A more useful comparison of technology levels is shown in Table 9, which summarizes the Types A through D robot populations by region.

It should be noted that these estimates are based upon reported or published data and do not include figures from several Western European countries or from most Eastern Europe countries, although it is known that robots are being used in those countries.

TABLE 9. - ESTIMATED PROGRAMMABLE ROBOT POPULATION AT YEAR-END 1980, BY REGION

Region	Total Robot Population (Types A, B, C and D)
North America	4,370
Western Europe	4,170
Eastern Europe	860
Asia	17,214

The automobile industry, that is, the automobile manufacturers and their suppliers, is the largest single industry using robots today. Table 10 shows the number of robots in use in 1980 in the automobile industry, by region. Also shown is the percentage of the total robot population so used.

TABLE 10 - ESTIMATED PROGRAMMABLE ROBOT USAGE IN THE AUTOMOBILE INDUSTRY AT YEAR-END 1980

Region	Automotive Robots (Types A,B,C and D)	Percent of Total Robots
North America	1,065	24%
Western Europe	1,688	40%
Asia	5,217	30%

Sources: Robot Institute of America, Japan Industrial Robot Association, National Robot Coordinators Reports, March, 1979 and March, 1980, Daiwa Securities America Inc., July, 1981, and others

A detailed breakdown, by automobile companies and suppliers, of the year-end 1980 automotive industry robot population is shown in Table 11. Data for this Table was derived from a variety of sources; magazine articles, internal reports, robot manufacturers, etc., and represents the best estimates of the current situation.

TABLE 11 - ESTIMATED PROGRAMMABLE ROBOT USAGE BY AUTOMOBILE MANUFACTURERS AND SUPPLIERS AT YEAR-END 1980

Region	Manufacturer/Supplier (Country)	Number of Robots A	B	C	D	TOTAL
North America	American Motors (U.S.)	6	-	4	-	10
	Chrysler (U.S.)	210	-	-	-	210
	Ford (U.S./Canada)	258	12	5	-	275
	General Motors (U.S./Canada)	389	36	25	-	450
	Suppliers (U.S./Canada)	60	10	50	-	120
	Sub Total	923	58	84	-	1,065
Western Europe	Alfa Romeo (Italy)	28	2	-	-	30
	British Leyland (U.K.)	34	6	-	-	40
	BMW (West Germany)	150	11	-	-	161
	Daimler Benz (West Germany)	40	51	-	-	91
	Fiat (Italy)	240	10	-	-	250
	Ford-Europe (U.K., W.Germany Belgium, Spain)	105	8	2	-	115
	Opel/Vauxhall-GM (W.Ger., U.K)	100	16	-	-	116
	Peugeot/Citroen/Chrysler (France, U.K.)	30	12	-	-	42
	Renault (France)	178	36	-	-	214
	Rolls Royce (U.K.)	2	1	-	-	3
	Saab (Sweden)	25	8	19	-	52
	Volkswagen (West Germany)	192	8	20	-	220
	Volvo (Sweden)	150	13	45	-	208
	Suppliers - Italy	8	12	5	-	25
	- France	10	2	6	-	18
	- Sweden	5	15	10	-	30
	- U.K.	7	3	-	13	23
	- West Germany	10	5	35	-	50
	Sub Total	1,314	219	142	13	1,688

TABLE 11 (continued)

Region	Manufacturer/Supplier (Country)	Number of Robots A	B	C	D	TOTAL
Asia	Ford (Australia)	14	-	-	-	14
	Fuji/Subaru (Japan)	50	15	5	-	70
	Honda (Japan)	100	16	10	-	126
	Isuzu (Japan)	2	-	-	-	2
	Mitsubishi (Japan)	250	20	750	-	1,020
	Nissan (Japan)	320	40	930	30	1,320
	Suzuki (Japan)	90	10	130	-	230
	Toyo Kogyo (Japan)	275	10	150	-	435
	Toyota (Japan)	420	30	850	-	1,300
	Suppliers (Japan)	110	60	470	60	700
	Sub Total	1,631	201	3,295	90	5,217
	Grand Total	3,868	478	3,521	103	7,970

Automobile manufacturing operations can be separated into several uniquely different groups, to which varied levels and types of automation are applied. These groups include:

- Component Manufacturing and Assembly
- Body Assembly
- Body Finishing
- Trim and Final Assembly

Each of these groups of manufacturing operations and the levels and types of automation utilized are described on the following pages.

CURRENT APPLICATIONS IN COMPONENT MANUFACTURING AND ASSEMBLY

Automobile component manufacturing and assembly covers a wide variety of processes, operations and materials. Typical automobile components where automation is employed to a significant degree include engines, transmissions, axles, sheet metal and plastic body panels, frame and suspension members, steering assemblies and electrical and electronics systems.

The processes involved include casting and forging, component (small parts) machining, pallet-transfer machining, stamping and molding, and assembly and testing. No particular automobile manufacturer or region appears to have any advantage in the automation of these processes; the technology is widespread and available to all.

Types A, B and C robots are used for a variety of operations associated with component manufacturing and assembly, handling either parts or tools.

In the foundries and forging shops, Type A, B, C and D robots are used in a variety of operations. New casting techniques and forming processes are also being employed. Examples of these technologies are shown in Table 12.

TABLE 12 - FOUNDRY AND FORGING TECHNOLOGY UTILIZATION

Region	Company (Country)	Technology
North America	Doeler-Jarvis (U.S.)	Unload die casting machines with robots, handling parts up to 75 pounds, about 50 robots in use.
		3000 Ton capacity die casting machine with robot unloader to produce parts for G.M. Hydra-matic
	Federal-Mogul (U.S.)	Hot forming of powder metal preforms for transmission components and bearing races.
	Ford (U.S.)	Unload die casting machines with robots, 8 robots in use.
	General Motors (U.S.)	Automatic pouring of V-6 cast iron engine blocks.
		Hot forming of powder metal preforms for transmission components.
		Unload die casting machines with robots, 7 robots in use.
		Flaskless (continuous, automatic) moulding lines for cast iron parts, robots transfer cast parts into die triming presses, 5 robots in use.
		New automatic rotary casting equipment installed in Central Foundry.
		Seven fully automatic forging presses being installed at Chevrolet Detroit Forge plant.
Western Europe	Alfa Romeo (Italy)	Robots load hot blanks into forging press and forged parts into triming press, 2 robots in use.
		Unload die casting machines with robots, 2 robots in use.
		Remove gates and risers and grind flash from castings with a robot.

TABLE 12 (continued)

Region	Company (Country)	Technology
W.Europe (Cont'd)	British Leyland (U.K.)	Grind flash from cylinder heads and engine blocks with a robot.
	Castings (U.K.)	Flaskless (continuous, automatic) moulding line for small malleable iron parts such as door hinge and spring brackets.
	Citroen (France)	Robot positions cores in molds.
	Daimler Benz (West Germany)	High-pressure water jet system to decore (remove sand from internal passages) aluminum cylinder blocks.
		Robot handling forgings at Unterturkheim Plant.
	Fiat (Italy)	Unload die casting machines with robots, 12 robots in use.
	Ford (West Germany)	Robot handling forgings at Koln plant.
	Metal Castings (U.K.)	Unload die casting machines with robots, 21 robots in use.
		Robot installed on 600 ton die caster to load inserts and unload aluminum automobile parts.
	Renault (France)	Automated cylinder liner machines (complete from pouring of metal to removing castings and placing them in baskets on a conveyor).
	Tube Investments (U.K.)	Robot handles axle components through upsetting (forging) operations.
	Volkswagen (West Germany)	Grind flash from engine blocks with a robot.
		Robot transfers cast crankshafts from conveyor to containers.

TABLE 12 (continued)

Region	Company (Country)	Technology
W.Europe (Continued)	Volvo (Sweden)	Grind flash from gear box castings with a robot.
		Clean molds with robot handling air jet.
		Load billets into forging press with a robot.
		Continuous path (Type B) robot spraying cores and molds in foundry.
Asia	Nippondenso (Japan)	Sixty robots (Types A and B and C) unloading die casting machines.
	Nissan (Japan)	Unload die casting machines with robots, 20 robots in use.
		High-speed automatic forging of gear blanks at 35 to 70 per minute.

In basic parts manufacturing, the new technologies in use include finish rolling of gears, laser and electron beam welding and hardening, Types A and C robot parts handling and a variety of inspection techniques. Examples are shown in Table 13.

TABLE 13 - BASIC PARTS MANUFACTURING AND INSPECTION TECHNOLOGY UTILIZATION

Region	Company (Country)	Technology
North America	Chrysler (U.S.)	Electron beam welding of two-piece die cast aluminum intake manifold, with computer-controlled part positioning.
	Ford (U.S.)	Automatic camshaft gaging system with automatic parts handling and computer interface.
		Transmission gear finish rolling machines, 3 machines.
	General Motors (U.S.)	Automatic handling and inspection system for pistons (2,000 per hour).
		Automatic handling and inspection system for valve rocker arms (9,000 per hour).
		Laser welder for Packard Electric Division to produce wire-to-terminal assemblies for on-board computer-control systems, to join wire made of unconventional materials to terminals at high production rates.
		Five laser welders for AC Spark Plug Division to assemble exhaust oxygen sensors for computer-controlled catalytic converter system.

TABLE 13 (continued)

Region	Company (Country)	Technology
Western Europe	British Leyland (U.K.)	Transmission gear finish rolling machines, 40 machines in place or on order.
	Borg-Warner (U.K.)	Transmission gear finish rolling machine.
	Fiat (Italy)	Laser welding of synchronizer rings to gears.
		Laser hardening of crankshafts.
		Laser surface hardening of gear selectors.
	Ford (U.K. & W.Germany)	Transmission gear finish rolling machines, 6 lines.
	Ford (U.K)	Two robots deburring machined suspension components.
	Ford (W.Germany)	Two robots deburring machined components.
	Kongsberg (Norway)	Highly-automated production line for axle half-shafts for volvo.
	Lancia (Italy)	Automatic gear cutting machines with automatic parts feeding.
		Electron beam welding of synchronizer rings to gears.
	Saab (Sweden)	Robots loading and unloading metal-cutting machines, 15 robots in use with lathes, broaches, drilling machines, gear shapers and milling machines.
	Volvo (Sweden)	Three robots handling and grinding components.
		In crankshaft department at Skovde Engine Plant, 40 of the 60 machine tools are equipped with dedicated robots to load and unload parts.

TABLE 13 (continued)

Region	Company (Country)	Technology
Asia	Nissan (Japan)	Fixed-sequence manipulators load and unload gear turning and cutting machines, 1,500 manipulators in use in the Yoshiwara Transmission Plant.

Automatic pallet-transfer machining lines are commonly used for machining operations on engine blocks and heads, gear boxes, axle housings and steering components. New technology applied to these lines includes automatic loading and unloading of parts, automatic gaging and adaptive control of cutting tools. Examples of high-technology transfer machining lines are shown in Table 14. Robots used for loading and unloading of parts are usually Type A.

TABLE 14 - HIGH-TECHNOLOGY TRANSFER MACHINING LINE UTILIZATION

Region	Company (Country)	Technology
North America	Ford (U.S.)	Multi-station transfer line for differential case machining, incorporating four CNC turning stations to perform 3-axis contouring; in-line gaging and automatic tool compensation.
		Large line to machine aluminum transmission extension housings, utilizing diamond tooling.
		Large Japanese transfer line to manufacture lock-up torque converter housings for automatic transmissions.
		46-Station transfer line to machine power steering rack pistons, with display of part clamping torque and in-line pallet inspection station.
	General Motors (U.S.)	11-Machine integrated manufacturing system to machine, assemble and test rear axles.
		37 Robots loading and unloading transmission case pallet transfer machining lines.
		Large in-line system to machine aluminum intake manifolds, using high-water-based fluid for coolant and transfer drive.

TABLE 14 (continued)

Region	Company (Country)	Technology
N.America (Cont'd)	General Motors (U.S.)	Incorporation of laser inspection systems in a valve lifter production line to inspect blanks before machining.
		40-Station line for machining clutch housings and 37-station line for transmission cases, with high-accuracy drives and bore gaging systems, which permit machining housing and case halves separately, instead of as assemblies.
		Programmable transfer lines for engine component machining at Cadillac and Oldsmobile.
		Flexible machining system -- NC machining centers and computer-controlled transporters being purchased from Comau (Fiat) for Chevrolet Gear and Axle.
		New high-speed pallet transfer line for machining steering knuckles at rate up to 200 sets (left-hand and right-hand) per hour, at Chevrolet Saginaw Manufacturing Plant.
Western Europe	BMW (West Germany)	Engine block machining line with in-line bore gaging and automatic tool adjustment.
		Crankshaft machining line with in-line heat treating and automatic 100% inspection of critical dimensions.
		Cylinder head machining line with robot deburring heads after machining.
	Lancia (Italy)	Transmission case machining line which handles five different cases.

TABLE 14 (continued)

Region	Company (Country)	Technology
W.Europe (Cont'd)	Opel (West Germany)	Three 45-station engine block machining lines, for Australia, Brazil and Germany Australian line will handle seven different blocks.
	Volvo (Sweden)	Four robots deburr gear box parts after machining.
		High-volume, three section transfer line for machining steering knuckles at rate up to 114 pairs per hour. Totally automatic, including loading, machining, gaging and tool adjustment.

Metal stamping and forming and plastics forming operations have been automated, to some degree, for some time. Mechanical transfer systems, non-programmable manipulators and Types A, B and C robots are used for these tasks. Some examples of recent innovations in these operations are shown in Table 15.

TABLE 15 - METAL AND PLASTICS FORMING TECHNOLOGY UTILIZATION

Region	Company (Country)	Technology
North America	A. O. Smith (U.S.)	Five robots used on three press lines to transfer frame rails and cross-members between stamping presses at 340 to 390 parts per hour.
	Bendix (U.S.)	In-line stamping system from Japan with automatic coil feeding, blanking. blank handling and stamping sections and a powered movable bolster for changing dies; for front suspension members.
	Ford (U.S.)	Four robots arc welding door frames.
	General Motors (U.S.)	Automated press and welding line to form and weld fender reinforcements, pierce and install clinch nuts at a rate of 1,440 parts per hour.
		Integrated high-speed transfer line to assemble, weld and hem flanges on aluminum and steel hoods.
		Automatic high-speed inspection system for engine valve covers with automatic leak tester, solid-state camera visual inspection, programmable controller and robot handling, at a rate of 1,200 per hour.

TABLE 15 (continued)

Region	Company (Country)	Technology
N.America (Cont'd)	General Motors (U.S.)	Three robots arc welding components at Delco Plant. Four robots welding J-Car trailing axles at Pontiac. Twenty-six robots loading and unloading stamping presses at Fisher Body Plants. Five robots arc welding in Bedford Foundry.
		Gamma-ray parts-detector system checking J-Car welded sheet metal assemblies for missing components.
	Hayes-Albion (U.S.)	14-Station automatic line for grinding and polishing weld joints of roll-formed and welded door glass frames, with automatic wheel wear compensation.
Western Europe	Alfa Romeo (Italy)	Transfer devices between large presses; large, coil-fed presses with transfer dies in place of series of small presses; gravity feeders on small presses; non-programmable pick-and-place devices to load and unload presses.
	Armstrong Patents (U.K.)	Computer-controlled vector bending machines for forming exhaust pipes; automatic assembly of mufflers; automatic welding of exhaust pipes; mechanical locking of pipes to mufflers instead of welding; automatic forming and welding of mufflers.
	British Leyland (U.K.)	Three robots arc welding front subframes and other components at Longbridge Plant.
	BMW (West Germany)	Nine robots arc welding components at Dingolfing and Munich Plants.
	Daimler Benz (West Germany)	Seven robots arc welding components at Unterturkheim, Mannheim and Sindelfingen Plants.

TABLE 15 (Continued)

Region	Company (Country)	Technology
W.Europe (Cont'd)	Fiat (Italy)	Automatic press-to-press transfer systems, including automatic loading and unloading of dies.
		Five robots arc welding components.
	Ford (U.K.)	6-Station press line for one-piece body sides, with non-programmable manipulators for loading and unloading and automatic press-to-press transfer.
	Ford (West Germany)	One robot arc welding components at Koln. One robot loading and unloading stamping press at Koln.
	Opel (West Germany)	Sixteen robots arc welding front suspension and rear axle components.
	Peugeot (France)	Four robots arc welding components at Peugeot and Citroen Plants.
	Renault (France)	Automatic loaders and unloaders for stamping presses; 6-press line for door frames with automatic loading, transfer and unloading at 600 parts per hour; automatic bumper polishing and plating lines.
		Ten robots arc welding components.
	Saab (Sweden)	Seven robots arc welding components.
	Tube Investments (U.K.)	One robot arc welding rear axle housings.
	Volvo (Sweden)	Four robots arc welding components.

TABLE 15 (Continued)

Region	Company (Country)	Technology
Asia	Fuji (Japan)	Thirteen robots arc welding rear suspension crossmembers and rear suspension arms.
	Honda (Japan)	Seven-press bodyside stamping line at Sayama Plant with robots to load and unload presses, operates on 5-second cycle.
	Mitsubishi (Japan)	Three robots arc weld brackets to rear axle housings.
	Nissan (Japan)	Four robots arc weld engine mounting brackets and seat frames.

Component assembly and testing operations have often been highly labor intensive, with automation used primarily for transfer of parts between manual work stations. The recent trend is to incorporate automation for assembly, inspection and testing, as well as for parts handling, as shown in examples in Table 16. Types A and C robots are used in these operations.

TABLE 16 - AUTOMATED ASSEMBLY AND TESTING UTILIZATION

Region	Company (Country)	Technology
North America	Chrysler (U.S.)	Semi-automatic, non-synchronous carousel transfer line for trans-axle assembly. Twenty-four station line produces 183 assemblies per hour at 100% efficiency.
	Ford (U.S.)	Laser gage to inspect for washers on gear carriers; non-contact gage to verify rear axle gear ratios.
		Computerized engine hot test system with 38 test stands, 4 diagnostic stands and 6 repair stations, served by automatic non-synchronous engine handling system.
		Two 65-station, 3-loop systems to automatically assemble, inspect and test steering gear rack and pinion assemblies at rates of 240 per hour.
		156-Station, 3-loop system to automatically assemble, inspect and test front-wheel-drive transaxle assemblies.
	General Motors (U.S.)	Automatic assembly machine for flow control valves for power steering pumps.
		Five automatic assembly and welding systems for catalytic converters, with robots packing finished products into shipping containers.

TABLE 16 (Continued)

Region	Company (Country)	Technology
N.America (Cont'd)	General Motors (U.S.)	Eight robots assembling air conditioner blower motors; one robot assembling motor commutators to armatures; one robot installing screws in carburetors. Several transmission assembly systems with automatic parts rejection, functional testing, size gaging,shim selection and bolt feeding and torquing. Automated hot- and cold-test systems for 1.8 liter and 4.1 liter engines. One robot inserting wear sensor in brake shoes. One robot palletizing magnet assemblies for radio speakers. Computerized vision systems inspecting head assemblies for keepers in valve springs. Laser inspection system checks surfaces of valve lifter bodies.
Western Europe	Alfa Romeo (Italy)	Robot deburrs engine front cover, inserts bushing and drives studs.
	British Leyland (U.K.)	11-Station transfer machine to install valve guides and valve seat inserts in aluminum cylinder heads. 14-Spindle automatic bolt tightener with torque/angle control for cylinder head-to-block assembly.
	BMW (West Germany)	Automated pallet-transfer engine assembly line, with all lifting and fastening mechanized; automated cylinder head assembly line, both with computer monitoring; about 60% of operations are automated.
	Fiat (Italy)	Robot assembly and torque testing of steering gear tie rod assemblies; semi-automatic assembly of engines, using robots.

TABLE 16 (Continued)

Region	Company (Country)	Technology
Western Europe	Ford (West Germany)	Robot loads and unloads automatic leak testing machine for transmission cases.
	Volvo (Sweden)	New engine manufacturing plant, with self-propelled, wire-guided, computer-controlled carriers to transport engines through assembly area, "group" or "team" assembly concept, computerized, automatic hot testing (including emissions tests) after assembly.
Asia	Nippondenso (Japan)	High speed automatic assembly lines for automotive instrument assembly. Fuel gage assembly line handles 60 different assemblies in small batches (as many as 200 batches per day), operates on a one-second cycle and produces 500,000 per month on a single shift.
	Nissan (Japan)	Two pallet-transfer transmission assembly lines, with 60% of operations automated, including component insertion and fastener tightening.

CURRENT APPLICATIONS IN BODY ASSEMBLY

Automobile body assembly operations involve resistance (spot) welding of body panels into major subassemblies, welding of these subassemblies into a body shell, metal finishing, dimensional inspection and mechanical installation of components such as doors, hoods and trunk lids. It is in the welding operations that the highest degree of automation is to be found. Two approaches to automated welding are used, special-purpose multiwelders and Type A robots and most manufacturers utilize a combination of both technologies.

Table 17 shows the extent of automation of welding operations of the major automobile manufacturers. Also shown are the numbers of industrial robots used in welding operations. Data for this Table was derived from a variety of sources; magazine articles, internal reports, robot manufacturers, etc. and represents the best estimates of the current situation.

TABLE 17 - ESTIMATED PERCENTAGE OF BODY WELDING DONE WITH AUTOMATION (MULTIWELDERS AND ROBOTS) AND NUMBER OF ROBOTS WELDING AT YEAR-END 1980

Region	Manufacturer (Country)	(Percent) Automated Welding		(Type A) Number of Robots Welding
North America	American Motors (U.S.)	25		5
	Chrysler (U.S.)	75		206
	Ford	60		240
	General Motors (U.S./Canada)	45		220
	Regional Average	52%	S/T	671
Western Europe	Alfa Romeo (Italy)	40		10
	British Leyland (U.K.)	60		30
	BMW (West Germany)	85		146
	Daimler Benz (West Germany)	80		40
	Fiat (Italy)	75		220

TABLE 17 (Continued)

Region	Manufacturer (Country)	(Percent) Automated Welding		(Type A) Number of Robots Welding
W.Europe (Cont'd)	Ford-Europe (U.K., West Germany, Belgium, Spain)	45		100
	Opel/Vauxhall-GM (West Germany, U.K.)	60		100
	Peugeot/Citroen/Chrysler (France, U.K.)	50		24
	Renault (France)	90		178
	Rolls Royce (U.K.)	0		0
	Saab (Sweden)	85		80
	Volkswagen (West Germany)	95		150
	Volvo (Sweden)	95		150
	Regional Average	72%	S/T	1228
Asia	Ford (Australia)	25		2
	Fuji/Subaru (Japan)	85		20
	Honda (Japan)	80		81
	Isuzu (Japan)	40		2
	Mitsubishi (Japan)	80		200
	Nissan (Japan)	95		320
	Suzuki (Japan)	60		80
	Toyo Kogyo (Japan)	80		250
	Toyota (Japan)	85		300
	Regional Average	89%	S/T	1255
	Overall Average	70%	Grand Total	3154

Table 18 shows some examples of body assembly technology which are noteworthy because of either the extent of automation or the uniqueness of its application.

TABLE 18 - AUTOMATION TECHNOLOGY UTILIZATION IN BODY ASSEMBLY

Region	Company (Country)	Technology
North America	Chrysler (U.S.)	Belvidere, Illinois plant uses Robogate (Fiat) system with 50 robots to weld Omni and Horizon body shells -- about 90% of welding is automated.
		Detroit (Jefferson) and Newark, Delaware plants use Robogate (Fiat) systems and total of 128 robots to weld K-Car body shells; about 98% of welding is automated.
		St. Louis Plant uses indexing body welding line and a total of 14 robots to weld body shells.
	Ford (U.S.)	Four robots with contact probes, programmable controller and computer for data analysis check 150 dimensions on car bodies at a rate of 5 to 6 per hour.
	General Motors (U.S.)	Lakewood, Georgia plant uses four robots on continuous-moving line to weld body shells.
		Lordstown, Ohio and South Gate, California plants each use 36 robots to weld body shells and two robots with laser gages for dimensional checking of bodies after welding.
		Willow Run, Michigan plant uses two robots with force feedback to wire brush weld joints, after welding, before painting.

TABLE 18 (Continued)

Region	Company (Country)	Technology
Western Europe	British Leyland (U.K.)	Longbridge plant uses two four-stage multiwelders for underbody welding, two three-stage multiwelders and 28 robots, on two lines to weld ADO 88 body shells. Body shell welding incorporates checking fixtures after last multiwelder to check 22 critical dimensions before robot welding. About 98% of welding is automated.
	Daimler Benz (West Germany)	Sindelfingen plant has most highly mechanized body assembly operations in Europe, with multiwelders and robots performing virtually all welding automatically.
	Fiat (Italy)	Mirafiori plant has 3-stage multi-welder with automatic checking station after and 23 robots welding Model 131 bodies, multiwelder and 18 robots welding Model 132 bodies. Cassino plant has 2-stage multiwelder for Model 126 bodies, 45% of welding is automatic; multiwelders for Model 128 bodies, 63% of welding is automatic; multiwelders for Model 127 bodies, 83% of welding is automatic; multiwelders for Strada underbodies and Robogates for bodysides and body shells with 57 robots, 60% of welding is automatic.
	Ford (U.K./West Germany)	Halewood plant has multiwelders and 39 robots for underbodies, bodysides and body shells, about 90% of welding is automatic. Saarlouis plant has multiwelders and robots for underbodies, bodysides and body shells. Cologne plant has 25 robots spot welding body shells.

TABLE 18 (Continued)

Region	Company (Country)	Technology
W.Europe (Cont'd)	Peugeot (France)	3-Stage multiwelder and 15 robots weld body shell.
	Renault (France)	Flins plant has multiwelders for R5 subassemblies, underbody and body shells, 48% of welds are automatic; multiwelders for R12 subassemblies, underbody and body shell, 46% of welds are automatic; multiwelders and 12 robots for R18 subassemblies, underbody, bodysides and body shell, 82% of welds are automatic. Douai plant has multiwelders and 96 robots for R5 and R14 subassembly, underbody, bodyside and body shell welding.
	Saab (Sweden)	Trollhattan plant has multiwelders and 10 robots for Model 900 subassembly, underbody, bodyside and body shell welding, 98% of welding is automatic.
	Volvo (Sweden)	Torslanda plant has multiwelders and 46 robots for subassembly, underbody, bodyside and body shell welding, 95% of welding is automatic. Two robots with contact probes and computer interface check body dimensions after robot welding.
Asia	Fuji Heavy Industries (Japan)	Gunma plant has multiwelders and seven robots for subassembly, underbody, bodyside and body shell welding for Datsun and Subaru body welding, 89% of welding is automated.
	Honda (Japan)	At Suzuka plant, 80 robots and several special-purpose multiwelders fit and weld body shells. More than 80% of welding is automatic.

TABLE 18 (Continued)

Region	Company (Country)	Technology
Asia (Cont'd)	Mitsubishi (Japan)	Okazaki plant has multiwelders and 77 robots for subassembly, underbody, bodyside and body shell welding, about 80% of welding is automated; at Mizushima plant, 70 robots are used for bodyside and underbody welding; at Oihye plant, 35 robots are used for welding.
	Nissan (Japan)	Zama plant has 13 lines, 49 multi-welders and more than 50 robots to weld subassemblies, bodysides, under-bodies and body shells, about 96% of welds are made automatically; Oppama plant has multiwelders and 64 robots for subassembly, underbody, bodyside and body shell welding; Mirayama plant has multiwelders and 85 robots for subassembly, underbody, bodyside and body shell welding, 63% of welds are made automatically.
	Nissan (Japan)	At Tochigi plant, 6 Kawasaki 6060 arms in one station weld four different models of side assemblies; each robot arm makes 8 welds in 20 seconds. This station is followed by four more stations with 10 Kawasaki 2000 robots.
	Toyo Kogyo (Japan)	77 Robots have been installed in body shop for assembly of new small family car, the Familia or 323; previously, about 30 robots were being used. New plant at Kifu has 165 robots for Mazda cars.
	Toyota (Japan)	Takoaka plant has multiwelders and robots for subassembly, underbody, bodyside and body shell welding; New Tahara plant will have about 200 robots for welding installed in 1981.

CURRENT APPLICATIONS IN BODY FINISHING

Body finishing generally combines automation and manual operations, to varying degrees. After surface preparation (washing, phosphate treatment), most automobile manufacturers apply the first prime coat by electro-deposition in a dip tank. Both of these steps are automated. Final prime and color applications are sprayed.

Spray painting generally combines automatic equipment to cover the major exterior surfaces and hand "cut-in" spraying of interiors, door edges, underside of hoods and trunk lids, etc. Protective materials are applied to the underside of wheel openings, etc., for corrosion prevention and sound deadening, after other finishing operations are complete.

The extent of automation for final prime and color application and for undersealing is higher in Western Europe and Japan than in North America, with Type B robots used in place of manual spraying as shown in Table 19.

TABLE 19 - AUTOMATION TECHNOLOGY UTILIZATION IN BODY FINISHING

Region	Company (Country)	Technology
North America	American Motors (U.S.)	Stationary spray gun, electrostatic primer application, with manual "cut-in".
	General Motors (U.S.)	Stationary spray gun, electrostatic primer, sealer and color application, with manual "cut-in"; four paint lines, with four robots in each line, to spray primer and finish color on urethane plastic bumpers.
	Volkswagen (U.S.)	Automatic electrostatic primer and color coating, with manual interior spray.

TABLE 19 (Continued)

Region	Company (Country)	Technology
Western Europe	British Leyland (U.K.)	Four robots spraying underseal.
	Fiat (Italy)	Four robots spraying final color at Cassino plant, plans to increase number to 20; two vertical and one horizontal reciprocating spray machines, four fixed guns, four robots, automatic door openers spraying plastic powder primer at Termini plant.
	Ford (Belgium/West Germany)	Two robots spraying underseal at Genk plant; one robot painting engines at Cologne plant.
	Renault (France)	One robot spraying corrosion-resistant primer on underbodies, reciprocating spray machines and three robots spray primer and final color, with manual "cut-in", at Flins plant. Total of 26 robots spraying paint, primer and undercoat.
	Rolls Royce (U.K.)	One robot spraying rustproofing on underbodies.
	Volkswagen (West Germany)	Automatic electrostatic primer and color coating, with manual interior spraying.
Asia	Honda (Japan)	Reciprocating spray machines and manual "cut-in" for primer and color coating. Sixteen robots for prime, color and underseal at Sayama plant.
	Mitsubishi (Japan)	Two robots spraying underseal and ten robots spraying color at Okazaki plant.
	Nissan (Japan)	Reciprocating spray machines and manual "cut-in" for primer and color at Zama plant; three robots spraying underseal at Oppama plant; 50 robots used for spray painting in various plants.
	Toyota (Japan)	Fixed-gun electrostatic, reciprocating spray machines and manual "cut-in" for primer and color.

CURRENT APPLICATIONS IN TRIM AND FINAL ASSEMBLY

Trim and final assembly operations are still labor-intensive throughout the industry. With few exceptions, these operations are done on moving conveyor lines. Table 20 shows several approaches to automating these operations or to otherwise improving their efficiency.

TABLE 20 - AUTOMATION AND OTHER TECHNOLOGY UTILIZATION IN TRIM AND FINAL ASSEMBLY OPERATIONS

Region	Company (Country)	Technology
North America	Ford (U.S.)	Computerized electronic tester for instrument panel - checks 65 to 98 circuits in two minutes. For Escort/ Lynx carlines.
Western Europe	Fiat (Italy)	"Group" or "team" assembly of mechanical components, on fixtures in 12 pre-assembly bays, on self-propelled, wire-guided, computer-controlled carriers and automatic assembly of components to body in five automatic assembly machines, at Mirafiori plant.
	Volvo (Sweden)	"Group" or "team" assembly of trim components to body, chassis components on frame and final vehicle assembly on self-propelled, wire-guided, computer-controlled carriers, computer monitoring for quality and production control, at Kalmar plant.
Asia	Toyota (Japan)	"Stop" buttons installed at each station on assembly lines and workers are encouraged to stop the line any time they are unable to finish their task; has eliminated all on-line quality control inspectors. "Kanban" production control system which reduces in-process storage, floor space requirements, inventory and material handling requirements by frequent deliveries of small quantities of parts and material to the point of use.

As the foregoing sections of the report have shown, automobile manufacturing involves operations which range from making steel, glass, paints and plastics through casting, forging, stamping and machining to welding, assembly, painting and inspection. In all but the most basic operations, industrial robots are likely to be found.

The following table shows the approximate distribution of the automobile industry's robots among the significant applications and further, the distribution of robot types among these applications. The total population is for the year-end 1980 and the distribution is a best estimate; numbers for any specific application and/or type should be considered only as representative and should not be taken as absolute.

TABLE 21 - DISTRIBUTION OF ROBOT APPLICATIONS AMONG AUTOMOBILE MANUFACTURING OPERATIONS, YEAR-END 1980

Application	North America Type	North America Number	Western Europe Type	Western Europe Number	Asia Type	Asia Number	TOTAL Type	TOTAL Number
Spot Welding	A	671	A	1,228	A	1,255	A	3,154
Parts/Material Handling	A	88	A	38	A	62	A	188
	C	13	C	49	C	974	C	1,036
		101		87		1,036		1,224
Machine Tending	A	64	A	16	A	205	A	285
	C	6	C	46	C	1,100	C	1,152
					D	20	D	20
		70		62		1,325		1,457
Stamping Press Loading/Unloading	A	35	A	4	A	14	A	53
	C	8	C	17	C	650	C	675
		43		21		664		728
Component Assembly	A	11	A	4	A	68	A	83
	C	6	C	11	C	280	C	297
		17		15		348		380
Foundry/Forge	A	6	A	12	A	16	A	34
	B	4	B	12	B	-	B	16
					C	120	C	120
		10		24		136		170

TABLE 21 (Continued)

Application	North America Type	North America Number	Western Europe Type	Western Europe Number	Asia Type	Asia Number	TOTAL Type	TOTAL Number
Arc Welding	B	30	B	127	B	97	B	254
Spraying	B	22	B	58	B	93	B	173
Deburring	B	2	B	22	B	11	B	35
Die Casting	A	38	A	6	A	-	A	44
	C	47	C	17	C	75	C	139
			D	13	D	70	D	83
		85		36		145		266
Sorting/Inspection	A	10	A	6	A	11	A	27
	C	4	C	2	C	96	C	102
		14		8		107		129
TOTAL	A	923	A	1,314	A	1,631	A	3,868
	B	58	B	219	B	201	B	478
	C	84	C	142	C	3,295	C	3,521
	D	0	D	13	D	90	D	103
		1,065		1,688		5,217		7,970

There are several significant differences to note between robot utilization in North America, Western Europe and Asia, as shown in the preceeding table. First, more than 90% of the robots used in automobile manufacturing in North America and Western Europe are programmable, servo-controlled (Types A and B) units, whereas only about 35% of the Asian automobile industry's robots are of these types. One implication of this is clear: assuming comparable labor savings can accure with the use of either Types A and B or Types C and D robots and assuming that Types C and D robots cost about one-third as much as Types A and B robots, the Asian (that is, Japanese) automobile industry's utilization of capital for reduction of manufacturing costs should be significantly more effective than in North America or Western Europe.

Another difference is in robot utilization for body spot welding. Utilization for these operations in North America is about 63% and in Western Europe, about 72%. In Asia, by contrast, only about 24% of the robots are spot welding. This is relatively close to the overall percentage of automated (robot and machine/multiwelder) spot welding in North America -- 52%, and in Western Europe -- 72%, but dramatically different from Asia, where about 85% of all spot welding is automated. Here the implication is somewhat different, automatic welding equipment, other than robots (that is, press welders, machine welders and multiwelders), generally costs about one-third more than robot welding lines performing comparable tasks. Thus, the greater cost savings in Asian body shops resulting from a higher degree of automated welding is offset somewhat by the higher capital investment in equipment to eliminate manual welding operations.

Significant differences in robot utilization between Asia and the rest of the world are also evident in basic manufacturing and fabrication operations. In parts handling, machine tending, press loading, foundry, forge, deburring and die casting operations, the Asian automobile industry's robot utilization is two to four times as great as in North America or Western Europe (more than 63% in Asia, less than 29% in North America and less than 15% in Western Europe). This pattern of application is in total agreement with the Asian automobile industry's tendency to use the simpler robots; many basic manufacturing and fabrication operations do not require servo-controlled (Type A and B) robots.

PROJECTED TRENDS OF ROBOTS AND AUTOMATION

There is little doubt that automobile manufacturers worldwide intend to continue to introduce automation into their manufacturing processes, particularly for labor-intensive operations and for quality assurance. For the near term, at least, most automation systems will use proven, state-of-the-art technology rather than introduce radical new ideas.

Robot utilization will continue to grow. Pallet transfer lines for machining and assembly will become more efficient through the use of robots for loading and unloading and in-process gaging will be incorporated into more of these systems.

New production facilities are planned by many automobile manufacturers and these will incorporate more robots and automation.

Major captal expenditures to modernize facilities, to increase production capacity and to develop and produce new products are planned by many European and Japanese automobile manufacturers, as well as by North American manufacturers.

Following past practices, it is most likely that the automobile manufacturers will use these programs to increase the level of automation of their operations, as well.

Table 22 shows some of these capital expenditure programs.

TABLE 22 - NORTH AMERICAN, WESTERN EUROPEAN AND ASIAN CAPITAL EXPENDITURE PROGRAMS

Region	Company (Country)	Technology
North American	Chrysler (U.S.)	Over the next five years (1981-1985), Chrysler plans to spend $6.5 billion to bring to market at least two front wheel drive models each year. It will spend more than $75 million to change over their St. Louis Plant. (10)
	American Motors (U.S.)	AMC plans a seven year (1981-1987), $1.6 billion program, including a new Jeep (1983 model) and a new family of front wheel drive cars design by Renault. (10)
	Ford (U.S.)	Ford plans to spend about $2.5 billion annually through 1985 for plant conversions and for 22 major product programs, including four or five new vehicle platforms, ten new and modified engines, nine new and modified transmissions and eight new front wheel drive carlines. (10)
	General Motors (U.S.)	General Motors plans to spend about $32 billion in North America from 1980 through 1984, including three new assembly plants, conversion of two more assembly plants, construction and expansion of several component plants, as well as redesign of most of its products. (10)
	Honda America (U.S.)	Construction of a $200 million car-manufacturing plant is underway, with completion scheduled in 1982. The plant will have a capacity of 10,000 units per month. (10)
	Nissan USA (U.S.)	Construction is underway on a $500 million plant to produce 150,000 Datsun pickup trucks per year, beginning in August 1983. (10)

TABLE 22 (Continued)

Region	Company (Country)	Technology
N.America (Cont'd)	Volkswagen America (U.S.)	Conversion of a former missile plant in Sterling Heights, Michigan, is underway at a cost of $300 million. The plant is to be operational late in 1982. By 1985, another $400 million to $500 million will go into tooling, upgrading and expanding facilities. (10)
Western Europe	Daimler Benz (West Germany)	About $5 billion will be spend in the next five years to double production capacity and develop new engines and car models. (1)
	Fiat (Italy)	About $5 billion will be spent in the next four years to launch a new car model and increase market share. (1)
	Ford-Europe	About $5.8 billion will be spent through 1985 to develop new car and truck models and retool its plants for them. (2) A new $70 million plastic part manufacturing plant will be opened in West Germany in 1981. (3) About $5.3 billion will be spent through 1984 to expand production facilities. (3)
	General Motors	About $2.4 billion will be spent to increase manufacturing capacity, including an assembly plant and several components plants in Spain, a transmission plant and an engine plant in Austria, a components plant in France and a components plant in Northern Ireland. (4) (5)
	Volkswagen (West Germany)	About $5 billion will be spent from 1979 to 1981 on new products and retooling for them. (2)
Asia	Isuzu (Japan)	Production capacity will be increased from 420,000 units a year to 600,000 units a year within next two years. (6) $121 Million will be spent on expansion of production facilities. (7)

TABLE 22 (Continued)

Region	Company (Country)	Technology
Asia (Cont'd)	Toyo Kogyo (Japan)	$167 Million will be spent to build a new assembly plant with capacity to make 20,000 cars a month, to replace less-efficient assembly operations at the main plant. Will be operational by the fall of 1982. (8)
	Toyota (Japan)	New assembly plant, with capacity to make 10,000 units a month will be operational in spring of 1981. (9) A second new plant, with similar capacity may be built to start up in 1982. (6)

Sources:
(1) The Engineer, September 20, 1979, p. 15
(2) Wall Street Journal, September 12, 1979
(3) Wall Street Journal, January 16, 1980
(4) Wall Street Journal, February 21, 1980
(5) The Engineer, June 14, 1979, p. 9
(6) Wall Street Journal, December 12, 1979
(7) Wall Street Journal, November 13, 1979
(8) Wall Street Journal, December 23, 1980
(9) The Engineer, April 3, 1980, pp. 32-5
(10) Wards' Auto World, June, 1981, pp. 36-40

International Resource Development, Inc., in their survey, Industrial Robots in the 1980's, published in November, 1979, projected that the United States automobile industry would be purchasing at a level of $21 million worth of robots (400 units) in 1984 and $28 million worth (600 units) in 1989. Indumar, Inc., a market research company in Cincinnati, Ohio, in a private study in June, 1980, projected that robot purchases by the U.S. automobile industry in the next five years would amount to 1,085 units, about 25% of total robot sales. Frost & Sullivan, in their survey, The United States Industrial Robot Market, published in November, 1978, projected 1985 robot sales to the U.S. automobile industry at more than $53.8 million. At the 10th International Symposium on Industrial Robots in March, 1980, Mr. Joseph Engelberger, President of Unimation, the world's largest robot manufacturer, predicted that the robot population in the automobile industry worldwide would grow by 600-700 units in 1980 and then annually by 35% in the 1980's to reach approximately 50,000 by 1990.

Outside of the United States, the situation is much the same. The Japan Industrial Robot Association's (JIRA) 1978 report, The Present Status and the Future Outlook of Industrial Robot Utilization in Japan, November, 1978 indicated 1977 robot production value of 18 billion Yen and projected production valued at 290 billion Yen in 1985, with 30% to 35% being installed in the automobile industry. This same report indicated a trend toward replacement of multiwelders by robots because of product diversification and a shorter life cycle of car models. At the 10th ISIR also, the executive direction of JIRA reported that the annual production of robots in Japan in 1978 was about 10,000 units and 25 billion Yen, 114% of the previous year's production, and that the automobile industry accounted for 35%, in value, of the 1978 robot installations.

A recent report published by Daiwa Securities America Inc., placed the Japanese robot production in 1979 at 2,763 units with a value of $102 million and estimated the 1980 production at 3,200 units valued at $180 million. The same report projected Japan's 1985 robot production at 31,900 units with a value of $2.15 billion and 57,450 units worth $4.45 billion in 1990. In 1979, the automobile industry purchased about 38% of the Japanese robots and in 1980, the percentage is estimated at 30%. On this basis, the robot population in Japanese auto plants at year-end 1985 could be around 31,250 units.

In the North American automobile industry (and, most likely in the foreign auto industry as well) there will be, in addition to steady growth in robot population, a shift in applications, as shown in the following table:

TABLE 23 - PROJECTED INDUSTRIAL ROBOT APPLICATIONS IN THE NORTH AMERICAN AUTOMOBILE INDUSTRY, 1980--1990

Application Area	Percent of Total Automotive Robot Population				
	1980	1983	1985	1988	1990
Spot Welding and Arc Welding	65	45	35	25	20
Painting	2	8	9	10	11
Assembly	1	15	24	33	36
Fabricating and Manufacturing	20	22	24	26	28
Parts Handling and Transfer	12	10	8	6	5

The most significant changes in application through the decade will be the dramatic increase in robots for assembly operations, an increase in robots for painting and a leveling off of the robots in welding operations, the latter

resulting from the eventual installation of robots in most automobile body assembly facilities. Painting robots will also eventually replace all manual spraying operations and level off. Successful application of robots in assembly will facilitate automation of some of the most labor intensive operations in automobile manufacturing with a great potential for labor and cost reduction.

Table 24 summarizes some of the significant specific robot programs now being planned or underway. These are mostly applications of Types A and B robots, with Type A predominating.

TABLE 24 - MAJOR FUTURE ROBOT UTILIZATION PROGRAMS

Region	Company (Country)	Technology
North America	Chrysler (U.S./Canada)	Robogate body framing system and 64 Type A robots for St. Louis Assembly Plant, with startup in 1981. (1)
	General Motors (U.S./ Canada)	14,000 or more robots to be installed by 1990 in body assembly, parts assembly, machining, stamping, casting, painting and forging operations. (2)
Western Europe	Ford	Ford of Europe will add between 300 and 450 robots by 1982 at plants in Belgium and United Kingdom for new 1983 carline. (3)
	BMW	BMW has 192 addtional robots on order for delivery by the end of 1982. (4)
Asia	Toyota (Japan)	200 robots being installed in new Tahara factory during next twelve months and a further 200 in other factories during the following twelve months. (5) Unimation's licensee, Kawasaki has received an order from Toyota for 720 robots. (5)

Sources: 1) Chrysler Manufacturing Engineering, June 25, 1981
2) Automotive Industries, March 1981, pp. 41-45
3) Ford Manufacturing Staff, June 26, 1981
4) The Industrial Robot, Volume 7, No. 4, December 1980, p. 259; American Metal Markets/Metalworking News, May 18, 1981, p.21
5) Daiwa Securities America Inc. Report #25, July 28, 1981, p.24

The major U.S. automobile producer, General Motors, has publicized its robotics plans for the 1980's. The plan projects a robot population in General Motors North American Manufacturing and Assembly Operations of 14,000 by 1990.

The projected applications distribution for these robots is shown in Table 25.

TABLE 25 - PROJECTED ROBOT APPLICATIONS IN GENERAL MOTORS NORTH AMERICAN OPERATIONS

	Number of Robots in Use			
	1983	1985	1988	1990
Welding (Arc and Spot)	1,000	1,700	2,500	2,700
Painting	300	650	1,200	1,500
Assembly	675	1,200	3,200	5,000
Machine Loading	200	1,200	2,600	4,000
Parts Transfer	125	250	500	800
TOTAL	2,300	5,000	10,000	14,000

Source: Bache Institutional Research Newsletter, June 19, 1981, p.3
General Motors Manufacturing Staff Productivity Conference, November, 1980
Industrial Robots International, July 1981, p.2

Some specific future trends and plans in component manufacturing and assembly, in body assembly and in body finishing, can be seen. These are described on the following pages.

FUTURE TRENDS IN COMPONENT MANUFACTURING AND ASSEMBLY

Future plans for automation in automobile component manufacturing and assembly will involve robots, pallet transfer lines and special-purpose assembly machines. Examples of new technology and future plans are shown in Table 26.

TABLE 26 - FUTURE PLANS AND TRENDS IN AUTOMATION OF COMPONENT MANUFACTURING AND ASSEMBLY

Region	Company (Country)	Technology
North America	General Motors (U.S.)	Electro-optical gaging system for 100% inspection of crankshaft on production line.
		Five pallet transfer machining lines for front wheel drive transmission cases with 25 Type A robots (5 per line) for automatic loading and unloading.
		Two pallet transfer machining lines for blocks, two pallet transfer machining lines for heads, six to eight transfer machines for crankshafts and camshafts, 3-loop automated assembly system, 24-stand computerized hot test, diagnostic and repair system for new 1.8 liter four-cylinder engine.
		Two automated machining, welding and assembly lines for J-Car rear axle assemblies (cross beams, control arms, spindle plates and brackets, suspension mounting brackets, spring seats, bushing sleeves and braces). The second line will use four Type B robots to weld external reinforcements to the cross beams; robots may be added to first line later. Type A robots will also load and unload some sections of the lines.
		Robot based automated assembly system with several small Type A robots, small Type C robots and rotary index table to go into production operation early in 1982.

TABLE 26 (Continued)

Region	Company (Country)	Technology
Western Europe	British Leyland (U.K.)	Sixteen Type B robots for arc welding of Land-Rover chassis frames will be installed in 1981; one Type B robot for arc welding of light-gage sheet metal will also be installed in 1981.
	Daimler Benz (West Germany)	38 arc welding robots on order for component welding.
	Renault (France)	Type A robot with vision system will transfer crankshafts from a shipping pallet to a grinding machine; will be installed in 1981. Renault has begun production of small Type A robots for component assembly. About 30 have been installed in-house in 1980 and the company intends to produce about 140 in 1981; about 75% of production has been for its own use.
Asia	Aisin Seiki (Japan)	11-Station flexible machining line with automatic loaders and unloaders to produce 15 different brake cylinders being developed.
	Hitachi Seiki (Japan)	45-Station transfer line for automatic drilling, assembly, lubrication and leak test of cylinder heads.

FUTURE TRENDS IN BODY ASSEMBLY

The use of Type A robots for welding and inspection in body assembly operations will continue to show significant growth, as indicated in Table 27.

TABLE 27 - FUTURE PLANS AND TRENDS IN AUTOMATION OF BODY ASSEMBLY

Region	Company (Country)	Technology
North America	American Motors (U.S.)	20 Robots will be installed in Kenosha plant for production of Renault-designed front wheel drive products, startup in spring of 1982.
	Chrysler (U.S./Canada)	Robogate system with 64 Type A robots for body assembly at St. Louis plant in 1981.
	General Motors (U.S.)	Two robots with laser gaging system for J-Car body inspection at Lordstown plant; similar systems will be installed in four other plants by 1982.
		36 Type A robots for body shell welding on J-Car bodies at Lordstown and South Gate. Robogates and robots for body assembly at new plants in Orion Township, Michigan and Wentzville, Missouri and renovated plants in Leeds, Missouri; Baltimore; Janesville, Wisconsin; Arlington, Texas; Lansing, Michigan; Framingham, Massachusetts; Doraville, Georgia; Fremont, California; Toronto, Canada; Flint, Michigan; Lakewood, Georgia, (several hundred robots are involved); 20 robots for body shell welding at Norwood, Ohio plant.
	Nissan USA (U.S.)	About 100 robots will be installed in new U.S. plant for frame, body and cargo box welding with startup in 1983.
	Volkswagen of America (U.S.)	VW robots will be installed in Sterling Heights plant for mid-1982 startup.

TABLE 27 (Continued)

Region	Company (Country)	Technology
Western Europe	BMW (West Germany)	A total of 192 robots have been ordered for production of new Type 3 and Type 5 car bodies, with installation to be complete by the end of 1982.
	Ford	Between 300 and 450 robots will be installed in Genk, Belgium and Dagenham, U.K. for production of new carline in late 1982.
	Volvo (Sweden)	Two body framing lines and one body shell welding line with 32 robots now being installed.
Asia	Ford (Australia)	Twelve robots being installed for underbody spot welding; startup in late 1981.
	Nissan (Japan)	Nissan plans to buy 350 robots, mostly for welding, in the next few years.
	Suzuki (Japan)	34 Robots in body shop welding underbodies and bodysides for four different bodies.
	Toyota (Japan)	Toyota has ordered 720 spot welding robots from Kawasaki Heavy Industries -- 220 for delivery by March, 1981, 200 by March, 1982 and 300 by March, 1983. Kawasaki is delivering about 25 units a month. Toyoda Machine Works, a subsidiary of Toyota is producing about 1,000 modular robots a year, for use within Toyota manufacturing operations.

FUTURE TRENDS IN BODY FINISHING

The use of Type B robots for body finishing will show significant growth, as shown in Table 28.

General Motors has developed its own Type B robot, which it calls the NC Painter, and may produce them for internal use.

TABLE 28 - FUTURE PLANS AND TRENDS FOR BODY FINISHING

Region	Company (Country)	Technology
North America	General Motors (U.S.)	Eleven NC Painters now in operation in Doraville, Georgia plant. About 300 painting robots will be installed by 1983, most of which could be NC Painters.
	Nissan USA (U.S.)	A total of 37 robots will be installed in a completely automated paint system in the new U.S. plant.
Asia	Nissan (Japan)	Nissan plans to install about 300 robots for spraying operations (prime, underseal, color) in the next few years.

MANUFACTURING COST/AUTOMATION RELATIONSHIPS

Four major components of the cost of an automobile are product engineering, facilities and tooling, material and labor. With present market and regulatory pressures, changeover to new models and introduction of new products are frequent, and, as a result, product engineering, facilities and tooling costs are high. Size and weight reduction and corrosion protection programs have brought about changes in materials which often have increased material costs.

At the moment, the best opportunity for cost containment or reduction, therefore, lies in reducing labor costs. While some labor cost reduction can result from new product engineering, the primary means is through automation of manufacturing operations.

Other reasons for automation may exist, as will be cited in this section of the report. These include increasing productivity or production capacity, improving quality, reducing scrap or rework costs and coping with absenteeism and work stoppages, all of which have an impact upon manufacturing costs.

No hard data can be cited on the relationship between automobile manufacturing cost and the level of automation. However, based upon specific examples in Table 29 which follows, the conclusion can be drawn that higher levels of automation result in lower manufacturing costs. The examples relate to automation technology presented in the "Current Applications" sections of the report and are referenced to tables in those sections.

TABLE 29 - MANUFACTURING COST/AUTOMATION RELATIONSHIPS

Technology	Reference	Advantages
Robots unload die casting machines	Table 12 Doeler-Jarvis	Robots reduce labor by 60%, increase production by 15%, reduce scrap by 5%.
Robots load and unload forging presses	Table 12 Alfa-Romeo	Robots reduce labor by 50%, increase production 5% to 20%.
Fully automatic, flaskless molding machine for malleable iron	Table 12 Castings	Fully automatic Disamatic flaskless molding machine reduces manpower from 15 to 1.
Robot handles parts through upsetter	Table 12 Tube Investments	Robot reduces labor from 3 to 1.
Manipulators load and unload gear-making machines	Table 13 Nissan	1,500 manipulators loading and unloading gear-making machines reduced labor by 900 people (25%). Other automation in Yoshiwara transmission plant reduced work force by 300 people and increased output 10,000 units a month.
Gear rolling for finishing operations	Table 13 British Leyland Borg Warner Ford-Europe	Gear rolling instead of shaving for finishing lowered tooling costs and increased production by 2.5 times.
Fully automated in-line stamping system	Table 15 Bendix	System significantly reduces direct labor cost, reduces in-process inventory and increases productivity by 33%.
Robots handle stampings through presses	Table 15 Honda	7-Press line at Sayama Plant operates with four men instead of 28.
Robots arc weld stampings	Table 15 Nissan	Robots reduce labor from 12 to 2.
High-speed line for automatic assembly of fuel gages	Table 16 Nippondenso	High-speed automatic assembly line for fuel gages reduced operators from 125 to 25 people.

TABLE 29 (Continued)

Technology	Reference	Advantages
Robots spot weld body panels	Table 18 Fiat	Robots eliminate one man per shift per robot.
	Table 18 Volvo	Six robots on indexing transfer line reduce labor by 5.5 people per shift.
	Table 27 Suzuki	34 Robots in Kosai plant reduce labor from 320 to 250 people per day.
Multiwelders spot weld body panels	Table 18 Fiat	2-Stage multiwelder for body shell eliminated 40 workers per day.
Robogates, carriers and robots spot weld body panels	Table 18 Fiat	System operates with 25 men per shift (8 on the floor and the rest backup maintenance) instead of 125 men per shift for conventional, non-automated system.
Robots check dimensions of body shells	Table 18 Ford-U.S.	Robots check five to six bodies per hour, instead of one to two bodies per 8 hours; with same manpower.
Multiwelders and robots weld body panels	Table 18 Saab	Three multiwelder systems and ten robots weld subassemblies and body shells, producing 80,000 bodies a year with 32 direct laborers a day.
	Table 18 British Leyland	Multiwelders for underbody assembly make more than 600 spot welds. Thirteen men required, instead of 80. Robots and multiwelders for body shell assembly make more than 460 spot welds. 38 Men required instead of 138.
	Table 18 Nissan	At Zama plant, a total of 160 direct workers on two shifts produce 800 bodies per day. They handle parts, manually weld and maintain equipment. There are no indirect workers on the floor of the body shop.

Automation may be installed for reasons other than the cost of labor. In Sweden, for example group assembly and automated transfer of work, as typified by Volvo's Kalmar plant was instituted to reduce absenteeism and labor turnover (almost 20% at the main Volvo plant) and to improve product quality. Volvo's engine plant at Skovde also uses assembly teams; there, absenteeism and turnover is 10%, half the national average in Sweden, engine rework has dropped from 1% to less than 0.1% and the average time of 3.75 hours to build an engine is down from previous years.

In Italy and the United Kingdom automation is applied in critical manufacturing operations to reduce the impact of unauthorized work stoppages.

In Japan, automation is considered essential to meeting increasing production requirements with a labor force whose size is relatively fixed. Also in Japan, the lifetime employment policy still followed by larger companies makes long-term investment in automation more economically attractive than labor-intensive approaches.

INVESTMENT LEVELS FOR ROBOTS AND AUTOMATION

Although automation and other new technology can significantly reduce labor cost, increase productivity and solve labor problems, investment levels are often high, as shown in Table 30.

TABLE 30 - INVESTMENT LEVELS FOR ROBOTS AND AUTOMATION

Technology	Reference	Investment Level
Programmable transfer lines for engine components	Table 14 General Motors	Programmable (convertible) transfer lines cost 8% to 10% more than conventional transfer lines, which may cost from $10 million to $15 million.
High speed automatic assembly lines for automotive instrument and gages	Table 16 Nippondenso	High-speed automatic assembly line for batch assembly of fuel gages cost about $1 million.
Computer-controlled carriers and "group" assembly for engine manufacturing	Table 16 Volvo	Skovde engine plant cost about $50 million in 1974, 10% more than conventional plant of comparable capacity; produces 275,000 engines a year.
Robogates, carriers and robots for body welding	Table 18 Chrysler, Fiat, Table 19 Chrysler, General Motors	Robogate systems cost 30% more than multiwelders, transfer lines and robots and occupy twice as much floor space. Fiat's Robogate system with 27 robots at the Rivalta plant cost more than $20 million in 1977.
Multiwelder for spot welding body panels	Table 18 Fiat	2-Stage multiwelder for body shell cost $3 million in 1973.
Multiwelders and robots for body panel welding	Table 18 Saab	Hood welding line cost nearly $1 million, front end welding line cost $6 million, body framing line cost $3 million, robots cost over $1 million, in 1977.

TABLE 30 (Continued)

Technology	Reference	Investment Level
Computer-controlled carriers and "group" assembly for trim and final operations	Table 20 Volvo	Kalmar assembly plant cost about $20 million in 1973, about 10% more than conventional plant of the same size; produces 60,000 cars a year on two shifts. Conventional plan might produce 180,000 cars with same space.
Robots for body assembly, parts assembly, machining, stamping, casting and forging operations	Table 25 General Motors	General Motors' future robot purchases would cost between $70 million and $126 million, at today's prices, for 1,000 to 1,800 robots.

The actual population of robots in the North American automobile industry, by the end of the decade, could reach 35,000 units or more. Projections of this population growth are shown in the following table:

TABLE 31 - PROJECTED INDUSTRIAL ROBOT POPULATION IN THE NORTH AMERICAN AUTOMOBILE INDUSTRY, 1980-1990

	1980	1983	1985	1988	1990
Minimum Effort	1,065	2,600	4,700	10,800	18,500
Moderate Effort	1,065	4,050	7,500	16,200	22,600
Strong Effort	1,065	4,500	10,000	20,000	28,000
Maximum Effort	1,065	4,500	11,200	25,000	35,700

The estimated total cost of these robots, including engineering of the applications; systems development, design and fabrication; and implementation, but not including operating support expenses (that is, the initial investment only), in constant (1980) dollars, is shown in the following table:

TABLE 32 - CUMULATIVE COST OF INDUSTRIAL ROBOTS IN THE NORTH AMERICAN AUTOMOBILE INDUSTRY, 1980-1990 (Millions of Dollars)

	1980	1983	1985	1988	1990
Minimum Effort	120	300	550	1,200	2,000
Moderate Effort	120	450	850	1,800	2,500
Strong Effort	120	500	1,100	2,200	3,000
Maximum Effort	120	500	1,250	2,750	4,000

The "minimum effort" projections are based on the assumption that the domestic automobile industry will continue to experience lagging sales and strong foreign competition through the mid-1980's. Under such circumstances, the rate at which robots are added to the current population will not be accelerated from the present level and few new, innovative applications will be developed. The "moderate effort" projections assume some recovery of the domestic automobile market and a modest decline in interest rates, making more capital available for productivity improvements. The "strong effort" projections are based upon a similar rate of recovery of the market and interest rate decline, plus investment incentives such as tax credits, accelerated write-offs, etc., and technological advances such as low-cost sensory feedback systems. The "maximum effort" projections assume, in addition to the foregoing, direct subsidies for robot investments, government-funded worker retraining and/or relocation programs and other direct incentives.

POTENTIAL BENEFITS FROM ROBOTS

The primary benefit of industrial robot implementation is a reduction in the labor cost to produce a finished product. In some automobile manufacturing operations, added benefits such as energy and material savings (spray painting), more efficient utilization of assets (machine tending), reduction of scrap (die casting, plastic molding, etc.) and warranty cost reduction (in-process inspection) may accrue. These are, however, of significantly lesser magnitude than the labor cost savings.

Estimates have been made of the potential savings which the North American automobile industry can expect from the continued introduction of robots at various rates (as in Table 31). These estimates, which are shown in the following table, are based upon a number of factors, including labor savings, energy and material savings, higher output and reduced scrap and rework. Improvements in robot performance and efficiency, changes in applications patterns and hours of utilization were also considered.

In order to maintain production while individual workers on the line are taking their authorized breaks ("relief"), normal practice in North American auto factories is to temporarily replace these workers with "utility" or "relief" operators. Thus, for approximately every seven workers in production operations, there is an additional worker required. Robots, obviously do not require relief, therefore, each robot replaces not only the direct labor operators, but an increment of a relief operator. Robots, however, do require maintenance and repair. Thus, for each robot installed, there is an incremental increase in the indirect labor force in the plant. For these estimates, the relief allowance savings and maintenance allowance increase were considered to offset each other.

Not considered in the savings, however, were the normal "overmanning" allowance, which is included in work standards to cover authorized and unauthorized absenteeism or an allowance to cover the lower efficiency of temporary or permanent replacement workers.

Wage and fringe benefit costs used were based upon average 1980-1981 rates in the U.S. auto industry, in constant (1980) dollars (as were the estimated robot costs in the previous section).

TABLE 33 - AVERAGE ANNUAL SAVINGS PER ROBOT IN NORTH AMERICAN AUTOMOBILE INDUSTRY, 1980-1990
(Thousands of Dollars)

	1980	1983	1985	1988	1990
Direct Labor Savings per Robot/per Shift a/					
- Heads	0.9	0.9	1.0	1.1	1.2
- Dollars	34,700	34,700	38,600	42,400	46,300
Robot Utilization b/					
- 2-Shift (Percent)	70	55	45	35	30
- 3-Shift (Percent)	30	45	55	65	70
"Other Savings" Factor (Dollars) c/	7,000	8,000	10,000	12,000	13,000
Average Annual Savings per Robot	86.8	93.0	108.4	124.3	138.0

a/ Assumes increasing efficiency of robots through technological improvements, sensory feedback, etc.

b/ Spot welding, arc welding and painting are associated with car assembly operations which operate on 2 shifts a day; other applications are associated with basic manufacturing operations which operate on 3 shifts a day. The change in shift utilization reflects the change in applications as shown in Table 23.

c/ Energy and material (painting); higher output, reduced scrap and rework (fabrication and manufacturing) -- factor varies with percentage of utilization of robots for these operations.

Based upon the projected population of robots, under various conditions, as shown in Table 31, and the average savings per robot in Table 33, the estimated cumulative savings are shown in the following Table:

TABLE 34 - CUMULATIVE SAVINGS FROM INDUSTRIAL ROBOTS IN NORTH AMERICAN AUTOMOBILE INDUSTRY, 1980-1990 (Millions of Dollars)

	1980*	1983	1985	1988	1990
Minimum Effort	390	890	1,725	4,600	8,900
Moderate Effort	390	1,100	2,450	6,900	12,500
Strong Effort	390	1,150	2,900	8,500	15,000
Maximum Effort	390	1,150	3,100	10,000	18,500

*Including estimated cumulative savings prior to 1980

Another, perhaps more meaningful, expression of the estimated savings from robot implementation is contained in the following table which shows the approximate savings per car. These estimates are based upon the same total savings as in the previous table and assume an annual production rate ranging from 7.2 million units in 1980 to 8.6 million units in 1990. The estimates are in constant (1980) dollars.

TABLE 35 - SAVINGS PER CAR FROM INDUSTRIAL ROBOTS IN NORTH AMERICAN AUTOMOBILE INDUSTRY, 1980-1990 (Dollars per Unit)

	1980	1983	1985	1988	1990
Minimum Effort	12	33	67	158	297
Moderate Effort	12	52	107	237	363
Strong Effort	12	57	143	292	449
Maximum Effort	12	57	160	366	573

Industrial robots also provide other, less tangible, benefits to the automobile industry. Robot spot welding systems are an excellent example. Body sheet metal welding is one of the most costly operations in automobile manufacturing. It requires a large investment in facilities, including electrical power, compressed air and cooling water distribution; welding transformers and controls; special-purpose automation; conveyors and transporters. It also requires a large investment in tooling, including assembly jigs and fixtures, welding machines, welding fixtures and welding guns. Much of this tooling has a short life; it is either replaced or extensively revised whenever styling or model changes are made. At the present time, although annual styling changes are no longer common, "downsizing", new model introductions and shifts in production rates are causing frequent, major changes in body tooling and facilities in many plants.

There are basically three approaches to body assembly: minimum investment, automation and robotics. The minimum investment approach uses simple, low cost jigs and fixtures and mostly manual welding. This method is inefficient because of high direct labor costs and excessive handling of components from fixture to fixture (and/or extensive conveyor systems for handling). Quality tends to be poor because of the high reliance upon operators to properly position, clamp and weld parts; because of the multitude of fixtures which require continual repair and adjustment to maintain the proper interrelationship of parts; and because of frequent handling of components.

The automation approach requires a large capital investment and has essentially no salvage value. The method is efficient in that a minimum of direct labor is required. Quality is potentially high, but may be adversely affected by the complexity of the automation which is often difficult to adjust and maintain. In today's time of frequent, major changes in body tooling, the investment in the automation may not be recovered before it must be either scrapped or extensively reworked. Installation of new automation or changeover of automation on-site is generally a time-consuming task, requiring long shut-downs of plants to accomplish.

The robotic approach may not be as efficient as automation in terms of direct labor requirements or in utilization of floor space, but its inherent flexibility and reliability make it an attractive alternative. Quality is potentially high and robotic systems are generally easier to adjust and maintain than automation. Robots do not weld as quickly as automatic welders or, in fact, as quickly as manual welders, thus, the initial investment may approach that of automatic welders. However, the robots are not obsoleted by model or styling changes and modern robot welding systems are designed so that most of the associated jigs, fixtures and transport mechanisms are also salvageable. Changeover time for new models is also relatively brief.

The concept of programmable automation, as typified by industrial robots, is also being adopted for other manufacturing processes. Several "convertible" transfer machining lines have been recently installed in two domestic engine plants. These lines are designed to produce several related products with only simple adjustments and replacement of a few heads or cutting tools involved for changeover. Normally a conversion can involve up to 90% of the cost of a new line and several months downtime. These programmable transfer lines may cost 10% more than conventional lines, but the overall savings are significant.

IMPACTS OF ROBOTS AND AUTOMATION

The continuing introduction of robots will have an impact upon several classes of workers in the automobile industry, including unskilled laborers (that is, direct labor), skilled trades personnel (that is, maintenance personnel) and engineering personnel. Jobs will be lost in one sector and gained in others. A surplus in certain labor classifications will exist, concurrent with shortages in other labor classifications.

The most severe impact will be upon the direct labor force. Each robot installed today displaces about two workers a day. As robot's capabilities increase and applications shift to the manufacturing areas which tend toward 3-shift operations, the ratio of robots to workers displaced will increase, so that by 1990 each robot will displace more than three workers a day.

Offsetting the loss of direct labor positions somewhat is the requirement for maintenance and repair of the robots. On average, a robot requires about one-tenth of a manhour of maintenance and repair for each hour of operation. Thus, every ten robots installed in a factory require approximately one skilled trades person for each shift of operation. Exact ratios vary with the types of robots, severity of operations, numbers of robots working together or in related applications, etc. Although the robot's operating capabilities are expected to increase during this decade, implying more complexity and higher maintenance requirements, their reliability and self-diagnostic abilities will increase also. Thus, this ratio (unlike the direct labor ratio) is expected to remain relatively constant.

The loss of direct labor opportunities, the gain of skilled trades positions and the net effect upon hourly work availability is shown in the following table, for various rates of robot introduction. The robot population figures, which are included in the table for reference, and the levels of effort are as described in Table 31 and its supporting detail.

TABLE 36 - PROJECTED IMPACT OF INDUSTRIAL ROBOTS ON LABOR IN THE NORTH AMERICAN AUTOMOBILE INDUSTRY, 1980-1990

	1980	1983	1985	1988	1990
Minimum Effort:					
Number of Robots a/	1,065	2,600	4,700	10,800	18,500
Direct Labor Loss b/	2,200	5,750	12,000	31,500	60,000
Skilled Trades Gain c/	250	650	1,250	2,800	5,100
Net Loss	1,950	5,100	10,750	28,700	54,900
Moderate Effort:					
Number of Robots a/	1,065	4,050	7,500	16,200	22,600
Direct Labor Loss b/	2,200	8,900	19,100	47,200	73,200
Skilled Trades Gain c/	250	1,000	2,000	4,200	6,200
Net Loss	1,950	7,900	17,100	43,000	67,000
Strong Effort:					
Number of Robots a/	1,065	4,500	10,000	20,000	28,000
Direct Labor Loss b/	2,200	9,925	25,500	58,300	90,700
Skilled Trades Gain c/	250	1,125	2,600	5,300	7,700
Net Loss	1,950	8,800	22,900	53,000	83,000
Maximum Effort:					
Number of Robots a/	1,065	4,500	11,200	25,000	35,700
Direct Labor Loss b/	2,200	9,925	28,500	72,800	115,700
Skilled Trades Gain c/	250	1,125	2,900	6,300	9,900
Net Loss	1,950	8,800	25,600	66,500	105,800

a/ Data from Table 31

b/ Calculated from direct labor savings per robot, Table 33

c/ Based upon one skilled trades person per ten robots, per operating shift and shift utilization per Table 33

As Table 36 shows, more than two thousand direct labor positions have already been filled by robots in North American automobile factories. These robots have, however, created about 250 new positions in the skilled trades ranks. By 1985, under the most modest growth rate anticipated, another 10,000 direct labor jobs will be gone, while 1,000 new skilled trades jobs will be added. If the introduction of robots is pursued aggressively, the loss of direct labor jobs by 1985 could approach 30,000, with fewer than 3,000 new positions generated.

To some extent, attrition (retirements, quits, dischanges, etc.) will compensate for the job displacement. In the past, in fact, the North American automobile industry has tried to match the rate of introduction of robots to the attrition rate. However, the current state of the industry and the higher level of general unemployment (which tends to reduce the rate of voluntary terminations) coupled with the influx of foreign cars and the need to increase productivity and reduce costs will necessitate the abandonment of this policy and the acceleration of robot implementation. For the long term, the attrition matching approach would not be satisfactory anyway, since it would continue to shrink the available job market in the industry.

Further aggravating the job loss situation is the fact that many of the direct labor personnel displaced will not be qualified or trainable to take on the task of robot maintenance. Thus, most will not be reemployed in new positions in the automobile plants from which they are displaced by the robots. Also, because of the geographic separation of many of the car factories from the robot factories (as well as the same skills barriers just cited), few of these displaced auto workers will find employment in the robot industry.

Despite the potential job losses facing its members, the United Auto Workers has not and, according to a recent statement by one of its vice-presidents, will not oppose increased automation in manufacturing. Donald F. Ephlin, UAW Vice-President and Director of the union's Ford department, returning from a recent tour of Japan, stated that, "Handling

automation is a continuing problem. We will struggle with the human results of it". He added, "Automation is the way we have improved the standard of living of the workforce".

The UAW has been pressing the auto industry to provide retraining for workers affected by robots. It will also press for more job protections. Ephlin pointed out that Japanese auto workers, "have achieved somethings we haven't" - notably guaranteed job security and wages that are rising faster than the rate of inflation. He pointed out that the Japanese economy is growing so rapidly it allows the country to achieve its national goal of full employment while increasing its level of automation. "I don't see any national commitment to full employment here", he said. "1948 was the last time we looked at full employment. It's time we dusted it off."

Japanese auto workers and the Japanese automobile industry do not face the same set of circumstances as their North American counterparts. The Japanese employes in major corporations are guaranteed lifetime employment. In addition, all employes received two bonuses a year, which are based upon the company profitability. Japanese unions are not based on crafts, skills or occupations; a union is on a companywide basis and covers all members of the bargaining unit. Employes identify with the company, not with a skill and they are often shifted from one job to another within the company. The worker, not fearing loss of employment does not oppose automation; in addition, as automated production generally enhances quality and profit and consequently the bonus, the Japanese employes welcome the robots. Also, because robots are often used in dangerous, unhealthy and repetitious jobs, the employes consider production by robots as a good means of relieving monotonous and environmentally harmful tasks in manufacturing. Finally, the shortage of labor and the aging of the workforce will hasten the acceptance and implementation of industrial robots.

In Western Europe, the automobile industry is currently in a similar condition to North America's. The European labor unions' attitudes toward robotics vary widely from country to country, ranging from strongly supportive in Sweden through lesser degrees of support and opposition in West Germany, France, Italy and Belgium to rather strong opposition in the United Kingdom. However, despite lower sales and higher unemployment, the European automobile industry is implementing robot applications at a rate comparable to the rest of the world.

The increase in requirements for skilled trades personnel for robot repair and maintenance is creating a need for facilities and programs to provide basic training in several fundamental areas. Among these are fluid mechanics (pneumatics and hydraulics), mechanisms and electronics. Although specialized training in trouble-shooting and repair of specific robots is provided by either the manufacturer or the user of the robots, fundamental skills are also required. Currently, the North American automobile industry is experiencing a shortage of trainable skilled trades personnel to support their robot operations. The problem is compounded by the job/skills classification system in the industry which requires as many as three different maintenance personnel to remove and replace a defective component on a robot.

In the long term, the development of company-sponsored and/or company-administered basic or fundamental training programs may be required. The establishment of a multi-skill "robot repairman" job classification will also be necessary for cost effective robot maintenance. It is highly unlikely, however, that direct labor workers in North America will ever be trained and allowed to operate and maintain the robots associated with their tasks, as is the case in Japan.

There will be several impacts on the robot industry, as the North American automobile industry continues its implementation of robot applications. The most immediate of these impacts is on the ability of the robot manufacturers and distributors to deliver the desired quantities of robots in the time frames required, without diverting units from other customers.

Currently, the North American automobile industry purchases about one-fourth of all the robots manufactured or distributed here. If one assumes that this proportion of total output continues to be supplied to the auto industry, there could be shortages, based upon robot industry projections of production and sales. The following table shows projected robot industry output and automobile industry demand:

TABLE 37 - PROJECTED INDUSTRIAL ROBOT PRODUCTION AND SALES TO NORTH AMERICAN AUTOMOBILE INDUSTRY, 1980--1990

		1980	1983	1985	1988	1990
Total Annual U.S. Robot Production/Sales	a/	1,269	3,122	5,690	14,000	25,515
Annual Sales to North American Auto Industry	b/	317	780	1,421	3,497	6,379
New Robots Required - Minimum Effort	c/	0	900	1,200	2,600	4,400
New Robots Required - Moderate Effort	c/	0	1,450	1,800	3,300	3,200
New Robots Required - Strong Effort	c/	0	1,450	2,900	3,900	5,000
New Robots Required - Maximum Effort	c/	0	1,900	3,400	5,000	5,300

a/ Robot Institute of America forecast
b/ Assuming about 25% of total production
c/ From projections in Table 31

As the table indicates, the robot industry's apparent capacity to supply the automotive market falls short, particularly in the mid-1980's, under even the least demanding of implementation schedules. It is unlikely, however, that actual shortages of robots will exist. Additional manufacturers and distributors of robots are likely to emerge in the North American market and existing manufacturers and distributors may also temporarily allocate a greater portion of their output to the automotive industry.

The most likely new source of robots in North America will be Japan. At the moment, there are nine European and six Japanese robots, out of a total of twenty-eight brands, being marketed and/or manufactured in the U.S. The Japanese robot industry is already planning on significant exports. The annual production volume of their industry is projected to increase ten-fold between 1980 and 1985 to about 32,000 units and to almost double again between 1985 and 1990 to more than 57,000 units. About 16%, by value, of 1985 production is slated for export and about 20%, by value, of 1990 production (JIRA projections).

Thus, a secondary impact on the North American robot industry will be on its competitive position in one of its major home markets. In order to retain its sales in the important automotive market, the domestic robot industry will have to match the price, delivery, reliability, support and capability of the imports and keep pace with emerging technology as well. This latter requirement may be most difficult, in light of the comparative levels of effort in robotics research and development here and overseas, as described in an earlier section of this report.

Another impact will be on the robot industry's ability to provide support services to its customers. As previously mentioned, the automobile industry has reduced its staff of robot applications personnel. The automobile industry's requirements for skilled trades personnel and technicians is, at the same time, increasing. On the one hand, this means that the robot industry will be expected to provide applications and system

engineering services, a role which that industry was not previously required to perform for the auto makers. On the other hand, the robot industry will have to compete with the automobile industry for technicians and skilled tradesmen for their manufacturing and field service/support operations. Presently, due to a wide disparity in pay and benefits, the robot industry is losing qualified personnel to the automobile industry. Matching the wage and benefit levels of the automobile industry and maintaining an applications and system engineering support staff could prove very costly to the robot industry at a time when competition from overseas requires holding the line on prices and increasing expenditures for research and development.

Internally, foreign automobile manufacturers are facing many of the same problems as the domestic industry. As with the domestic automobile industry, however, these problems are not considered as serious deterrents to continued implementation of robots. No significant impact is seen on those foreign competitors using robots as a result of the North American automobile industry's robotics utilization, since comparable benefits will accrue to both. Naturally, those not using robots, or using robots to a significantly lesser degree are operating under a cost penalty.

As the North American automobile industry increases its utilization of robots and automation, the productivity of the industry should continue to increase. At the moment, the annual rate of increase in productivity averages about 3%. By comparison, the Japanese automobile industry has an average annual productivity increase of 6%. Because the Japanese are introducing robots and automation into their automobile manufacturing operations at a rate at least comparable to the United States, there is little likelihood that the U.S. will match or exceed Japan's productivity. A similar comparison holds true for much of the European automobile industry, as well. The net result is that the U.S. automobile manufacturers will have to continue to implement robotics and automation at a strong rate in order to just keep up with foreign competition.

As with foreign competition, the impact of robotics on domestic automobile manufacturers will relate to their respective levels of utilization. Currently, no one domestic automaker (except AMC) is at a significantly higher or lower level of robot use than any other. Announced plans, internal planning and industry observer projections all point to the domestic automakers and the foreign automakers with domestic manufacturing operations continuing to implement robots at rates which will keep them competitive.

In addition to providing a means to improve productivity, industrial robots have an impact upon the type of tooling installed in the auto plants (especially in the assembly plants) the planning of changeovers and, to some extent, the layout of the plants themselves. As described earlier, the flexibility of an industrial robot is of advantage for model changeover. An analysis and comparison of hard automation and robot welding systems on the same operation at two different plants has been made by a domestic automaker. This comparison indicated that the initial cost of the robot system was about two-thirds of the cost of the hard automation system and that the cost for a subsequent model changeover was about half. In addition, the lead time for the robot system retooling for the changeover was about two-thirds that of the hard automation and the actual changeover time was about one-third less.

The robot's flexibility is also advantageous for coping with sourcing changes, that is, the major changeover of a plant to produce a completely different carline. The reusability of the robot is particularly important here. For example, when Chrysler stopped production at the Lynch Road Plant, the fourteen robots which were welding there were put into storage. These robots are now being shipped to Chrysler's St. Louis Plant where they will join some robots already in use there and some new robots being purchased as part of a new welding system which goes into operation late in 1981. The changeover of the robots from Lynch Road will involve simply installing new welding guns on their arms and putting new instructions (programs) into their memories.

As more and more "flexible automation" (that is, robots) is installed, the cost of retooling for model or sourcing changes should become less. Automotive industry manufacturing personnel experienced with robotic systems estimate that as much as 20% of the normal cost of retooling an assembly plant body shop can be saved where robots are being used. In addition to savings in tooling, the typical changeover time can be reduced by about one-third. Assuming that a major model change in a single assembly plant body shop equipped with hard automotion can cost as much as $40 million and require several weeks of downtime, the robots could save more than $10 million.

The robotics approach will also affect the design and layout of assembly plants. For maximum flexibility and efficiency, guided-transport systems and robotic work cells may replace continuous moving conveyor lines, not only in the body shop, but in trim and final assembly areas as well. This approach may require as much as twice the floor space as a conventional plant of comparable production capacity. This was Fiat's experience with their "Robogate" installation in the Rivalta plant and Volvo's at the Kalmar assembly plant, which uses guided-transport systems throughout and requires nearly three times the floor space of a conventional flow-line (moving conveyor) plant of comparable production capacity. Industrial plant and material handling systems designers also estimate that floor space requirements and facility costs for component manufacturing plants may be 10% higher for the robots and guided-transport systems approach.

As previously reported, estimates of the cost to the North American automobile industry to purchase and install robots range from about a half billion to a billion and a quarter dollars by 1985 and from two to four billion by 1990. These expenditures are in addition to more than $42 billion which the domestic automobile industry plans to spend through 1985 for new plants and new products.

Although these robot program expenditures are modest in comparison to the overall spending level, they are still significant. They also tend to be discretionary programs, that is, the delay or cancellation of a robot program usually has little or no immediate negative impact and may, in fact, make capital available for other programs. The long-term effect of such a delay or cancellation, however, as was discussed previously, will be the loss of competitive position or advantage.

CONCLUSIONS

The automobile industry worldwide utilizes, in general, the same types and technology levels of automation in manufacturing operations. No significant technological developments appear to be unique to a particular manufacturer or region. Obvious differences in the use of specific automation technologies and in the overall level of automation utilization do, however, exist. These differences are related to a number of factors, including labor rates and availability of workers, product complexity and differentiation and levels of investment and investment priorities. Direct labor is a significant element in the cost of manufacturing of automobiles and automotive components. The introduction of automation can greatly reduce labor costs, thus, higher levels of automation should result in lower cost of manufacturing the product.

In general, the degree of automation of automobile component manufacturing appears to be about the same, worldwide. Body assembly (welding) operations are more automated in Western Europe and Asia (Japan) than in North America, as are body finishing operations. Final assembly operations are similar worldwide, with a few unique exceptions.

Automation and robotics levels will continue to rise throughout the automobile industry worldwide through the 1980's. The growth rate of the robot population will be in the range of 35 to 40 percent a year through the decade. By 1990, the robot population in the North American automobile industry could reach 35,000 units or more, at a cost of $4 billion. The total savings in manufacturing costs, at that level of robot utilization, would be around $18 billion. This continuing implementation of robots will have an impact upon the labor force. By 1990, more than 115,000 direct labor positions in the North American automobile industry could be taken over by robots; about 10,000 new skilled trades/technician positions would be generated.

Robots and automation are effective tools for improving productivity and quality. Thus, despite the cost and the impact upon employment opportunities, their use will continue to expand. At this time, there are no technological factors inhibiting robot implementation. The development and refinement of new technology to enhance robots' capabilities remain comfortably ahead of the need for such technology. For the short term (the next two to four years), the inhibiting factors will be the users' lack of experience and confidence, a shortage of capital and, in North America, a limited robot manufacturing capacity. Beyond the mid-1980's, however, most of these hinderances will disappear.

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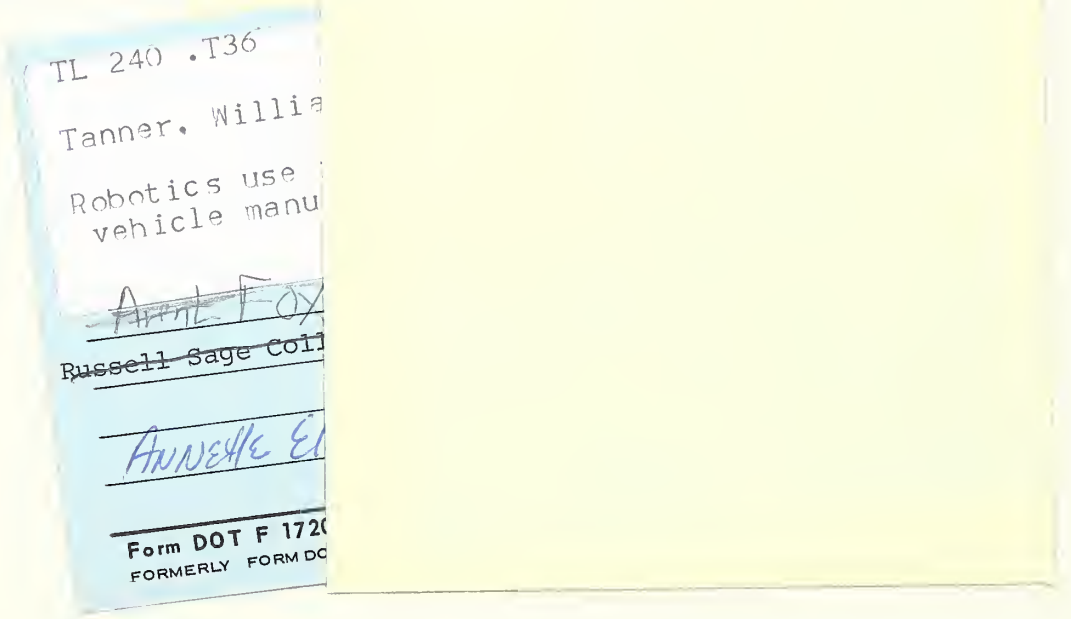
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